US Army Corps of Engineers
Construction Engineering Research Laboratories

USACERL Technical Report EC-95/03
October 1994

A Geographic Information System/Hydrologic Modeling Graphical User Interface for Flood Prediction and Assessment

by
Karen E. Frederickson, James D. Westervelt, and Douglas M. Johnston

Flood emergency decisionmaking may be improved through the development of computer-based systems that integrate such existing capabilities as data processing, precipitation forecasting and monitoring, streamflow forecasting, and hydraulic modeling to allow the simulation and comparative evaluation of various hydrometeorologic and reservoir release scenarios. Incorporating the spatial analysis capabilities of a Geographic Information System (GIS) can further increase system effectiveness by allowing the translation of simulation results into maps of flood inundation. A graphical user interface (GUI) can link the multiple components of a system and provide both procedural and decision support for emergency decisionmaking.

This study explored the technical feasibility of creating a prototype GUI for flood prediction and assessment. The developed prototype includes an on-screen operations flow chart that leads the user through the steps of flood simulation and assessment, eliminates the need for the decisionmaker to construct the simulation process, and allows rapid generation of and access to information useful for emergency decisionmaking. The prototype was evaluated by Omaha District Corps of Engineers personnel. Recommendations for further development include the addition of economic analysis capabilities and additional user prompts and online help.

USER EVALUATION OF REPORT

REFERENCE: USACERL Technical Report EC-95/03, *A Geographic Information System/Hydrologic Modeling Graphical User Interface for Flood Prediction and Assessment*

Please take a few minutes to answer the questions below, tear out this sheet, and return it to USACERL. As user of this report, your customer comments will provide USACERL with information essential for improving future reports.

1. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which report will be used.)

____

____

____

2. How, specifically, is the report being used? (Information source, design data or procedure, management procedure, source of ideas, etc.)

____

____

3. Has the information in this report led to any quantitative savings as far as manhours/contract dollars saved, operating costs avoided, efficiencies achieved, etc.? If so, please elaborate.

____

____

4. What is your evaluation of this report in the following areas?

a. Presentation: ____

b. Completeness: ____

c. Easy to Understand: ____

d. Easy to Implement: ____

e. Adequate Reference Material: ____

f. Relates to Area of Interest: ____

g. Did the report meet your expectations? ____

h. Does the report raise unanswered questions? ____

i. General Comments. (Indicate what you think should be changed to make this report and future reports of this type more responsive to your needs, more usable, improve readability, etc.)

5. If you would like to be contacted by the personnel who prepared this report to raise specific questions or discuss the topic, please fill in the following information.

Name:

Telephone Number:

Organization Address:

6. Please mail the completed form to:

Department of the Army
CONSTRUCTION ENGINEERING RESEARCH LABORATORIES
ATTN: CECER-IMT
P.O. Box 9005
Champaign, IL 61826-9005

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*

2. REPORT DATE
October 1994

3. REPORT TYPE AND DATES COVERED
Final

4. TITLE AND SUBTITLE
A Geographic Information System/Hydrologic Modeling Graphical User Interface for Flood Prediction and Assessment

5. FUNDING NUMBERS
IDIR
VW6

6. AUTHOR(S)
Karen E. Frederickson, James D. Westervelt, and Douglas M. Johnston

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Construction Engineering Research Laboratories (USACERL)
P.O. Box 9005
Champaign, IL 61826-9005

8. PERFORMING ORGANIZATION REPORT NUMBER
EC-95/03

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Copies are available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Flood emergency decisionmaking may be improved through the development of computer-based systems that integrate such existing capabilities as data processing, precipitation forecasting and monitoring, streamflow forecasting, and hydraulic modeling to allow the simulation and comparative evaluation of various hydrometeorologic and reservoir release scenarios. Incorporating the spatial analysis capabilities of a Geographic Information System (GIS) can further increase system effectiveness by allowing the translation of simulation results into maps of flood inundation. A graphical user interface (GUI) can link the multiple components of a system and provide both procedural and decision support for emergency decisionmaking.

This study explored the technical feasibility of creating a prototype GUI for flood prediction and assessment. The developed prototype includes an on-screen operations flow chart that leads the user through the steps of flood simulation and assessment, eliminates the need for the decisionmaker to construct the simulation process, and allows rapid generation of and access to information useful for emergency decisionmaking. The prototype was evaluated by Omaha District Corps of Engineers personnel. Recommendations for further development include the addition of economic analysis capabilities and additional user prompts and online help.

14. SUBJECT TERMS
geographic information systems
flood forecasting
spatial analysis
graphical user interface

15. NUMBER OF PAGES
52

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	SAR

Foreword

This study was conducted under Intra-Departmental Independent Research (IDIR); Work Unit VW6, "Graphical User Interface for Flood Prediction and Assessment." The technical monitor was Craig Fischenich, CEWES-EE-A.

The work was performed by Environmental Compliance and Modeling Division (EC), Environmental Sustainment Laboratory (EL), U.S. Army Construction Engineering Research Laboratories (USACERL). Dr. John Bandy is Chief, CECER-EC and William Goran is Chief, CECER-EL. The USACERL technical editor was William J. Wolfe, Information Management Office.

LTC David J. Rehbein is Commander and Acting Director, USACERL, and Dr. Michael J. O'Connor is Technical Director.

Contents

List of Figures and Table

Figures

Table

1 Introduction

Background

River flooding is one of the disasters that Army land managers and emergency planners must address. During emergency flood conditions, the National Weather Service (NWS) provides flood forecasts and warning services, while the Federal Emergency Management Agency (FEMA) directs flood response activities. The U.S. Army Corps of Engineers (USACE) may assist these agencies, particularly where Corps' reservoirs and other projects influence flood conditions. By regulating the discharges from its reservoirs, the Corps may help to minimize flooding downstream or to delay flooding until downstream areas are evacuated or other necessary actions are taken (Fischenich 1992). Rapid generation and assessment of information on downstream flood extent based on predicted climatic conditions and reservoir discharge schedules would enhance the Corps' contribution to real-time flood response. Already available computer packages make it possible to track storms, predict storm paths, simulate overland and channel flows, estimate river depths, and overlay flood extents on digital data bases containing human and economic information. Graphical user interfaces (GUIs) and geographic information system (GIS) tools can be developed to help Corps' district and division offices generate this information by seamlessly linking underlying computer models into a decision support system (DSS).

Implementation of hydrologic models and geographic information systems within a decision support system can allow planners with limited expertise in hydrology to rapidly generate and assess information related to flood conditions and control strategies. While current literature establishes the use of GISs within floodplain management studies for estimation of floodplain extent and expected long-term economic and other impacts from flooding, the use of GISs within emergency response systems is not yet a well-documented practice (Cotter 1989; Depodesta et al. 1991; Purves et al. 1991; Thompson et al. 1991).

Several factors have limited the real-time systematic use of modeling and GIS capabilities for flood prediction and assessment. One factor is that real-time flood prediction and assessment requires *multiple components*, including precipitation forecasting and monitoring, hydrologic and hydraulic modeling, spatial analysis and query, and graphical display. The varying data and procedural requirements of these

components usually demand time-consuming data translation and editing. Another factor limiting real-time use is that *multiple stages* of analysis are required for flood prediction and assessment, including the selection of models, the selection of data sources, and the interpretation of results. Because emergency response is infrequently practiced, questions regarding the proper sequence of tasks are likely to arise and hinder progress toward the creation of information useful for decisionmaking. Furthermore, the typical output of hydrologic and hydraulic modeling components are peak discharges at point locations, and water surface elevations at specified channel cross-sections. This output may not be immediately useful to the decisionmaker attempting to assess downstream impacts from flooding: such analyses require anticipated depth-over-time information. Manual interpolation of modeling results into more informative maps, graphs, and charts is time consuming and does not support real-time flood assessment.

Objective

The objective of this report is to describe the development of a graphical user interface (GUI) for an emergency flood prediction and assessment system. This system provides procedural support and improved information transfer to the user.

Approach

The Readiness Management System (RMS), conceived and developed by Omaha District U.S. Army Corps of Engineer staff, was chosen as the basis for the development of a prototype GUI (Omaha District COE). The purpose of RMS is to improve flood response time through accelerated generation, retrieval, and assessment of flood data (Fischenich 1991). As such, RMS provided a good basis for demonstrating the potential for creating GUIs that unify existing computer technologies into tools or systems for emergency decisionmaking. GUI and GIS capabilities support accelerated retrieval and assessment of data. An analysis of RMS was conducted to characterize the potential user, system tasks, user perceptions and terminology, and desired software components. A prototype GUI was subsequently developed and demonstrated at Omaha during the Oahe Dam Safety Exercise in September 1992. The prototype was evaluated based on interface standards established in current literature on interface design. Potential users of the GUI provided a general evaluation of the system, which is also documented in this report.

Scope

The GUI prototype was specifically designed to integrate the components of RMS selected by Omaha district to model flooding and impacts on the Missouri River from the Oahe Dam, Pierre, SD, downstream to Big Bend Dam at Fort Thompson, SD. Several of the system components chosen by Omaha District are well accepted tools, such as the river modeling software developed by the Hydrologic Engineering Center (HEC) (Feldman 1992). Other components constitute relatively new and as-yet unproven technology. This report does not attempt to evaluate the accuracy of the modeling components, but rather to demonstrate how modular GUI programs can permit the integration of independently developed software systems into a single system for use in rapid flood prediction and assessment. The interface does not alter the functioning of any individual software component, but rather links the data flows between components and provides a cohesive environment for system use.

This interface is not intended to completely eliminate the need for hydrologic and hydraulic modeling expertise during flood simulation. Data translation and editing not requiring expert judgment is computer automated, but some model input tasks require hydrologic or hydraulic expertise to correctly reflect real-time conditions.

Mode of Technology Transfer

The research documented within this report will contribute to continued research and development of a GUI for flood prediction and response, to be conducted at the U.S. Army Corps of Engineers Cold Regions Research and Engineering Laboratory (CRREL).

2 Approaches to Emergency Flood Prediction and Assessment

Computer-Based Systems

Computer-based systems have been developed for real-time flood forecasting. These systems are based on the control of a number of techniques using interactive software. Common capabilities integrated within these systems include data acquisition and processing, precipitation analysis, streamflow forecasting, reservoir system analysis, and graphical display of data and simulation results (Unver, Mays, and Lansey 1987, pp 620-638).

Feldman (1992) provides an overview of the numerous modeling tools developed at the Hydrologic Engineering Center (HEC) for water control applications. The existing suite of HEC models includes the HEC-1F model, which can be used for computing expected *annual* economic damage for different flood control alternatives based on historic or forecast data (USACE 1989). The HEC-5 model for the simulation of flood control and conservation systems operates reservoirs to minimize flooding at specified control points within the channel, although it does not indicate expected flooding in areas beyond the channel (Feldman 1992, p 250). The HEC-2 model generates water surface elevations at defined channel cross-sections. Computer-based *systems* have been created specifically for real-time flood assessment. Tennessee Valley Authority (TVA) software systems have been developed to provide rapid evaluation of a large number of (reservoir) operation alternatives and an improved information base for decisionmaking (Brown and Shelton 1986, pp 409-418). Suggested applications include the estimation of flood profiles, although not of flooded area. A decision-support computer model, BRASS (basin runoff and streamflow simulation), was developed by Savannah District COE to improve real-time prediction of flood discharges and stages, and to aid in flood management decisions within the Savannah River System (Colon and McMahon 1987, p 177). BRASS is used to generate information such as critical flood stages, discharges, and maxmin data in tabular output and printer plot format (McMahon 1989, pp 125-127).

A computer-based flood prediction sequence is described by Hoggan et al. (1991, pp 1061-1066). The sequence begins with the calculation of stream flow, including the contribution from tributary inflows. Stream flow data are collected from automated

stations, and headwater and tailwater elevations from dams located within the modeled reach. Flow rates are determined from stage values for selected sites using stage/discharge functions encoded within the computer system. For ungaged drainage areas, rainfall data is collected from recording stations and flow rates determined by hydrologic models. Flood routing models are used to calculate water surface profiles at specific points within the described channel. A geometric model is required to describe cross sections and reach lengths. Depending on the hydraulic model chosen, required input data may include computed or gaged stream discharge, flow regime, starting water surface elevation, and channel roughness. The final output of the flood prediction system may include computed discharge and stage hydrographs at major inflow points and other prespecified locations within the systems as well as water surface elevations at cross-section locations.

This system output may be used to warn emergency management centers of dangerously high discharges or stages. It does not, however, give an explicit indication of the relationship between reservoir release and downstream impacts, and is thus of limited use to help decide reservoir release. The output becomes more useful to the decisionmaker when it is translated into maps of flood extent and degree that can be used to predict impact on the population and likely land use and site damage. Manual interpolation of modeled water surface elevations into such maps is very time-consuming however, and usually requires a good understanding of the terrain of the modeled area. The subsequent overlay of site, infrastructure, and land area maps to gain the flood impact information is also a very time-consuming task when done manually.

Spatial Analysis With Geographic Information Systems (GIS)

The incorporation of the spatial analysis capabilities of a GIS into flood response systems can increase the effectiveness of such systems. In addition to increasing the speed and scale of data manipulation, GIS can also enhance the interpretation of typical hydrologic and hydraulic model output. A GIS may be used to automate the interpolation of channel water surface elevations into water surface elevation maps, to overlay water surface maps onto topographic maps to determine flood depth, and to identify sites lying within the flooded area.

Both hydrologic and hydraulic models may be linked to GIS to support flood prediction. While the use of GIS in conjunction with hydrologic and hydraulic models is not a new concept (Shea et al. 1993, p 112), it has become more widespread and sophisticated in relation to water resources applications with the increase in the availability and sophistication of GIS. Kurt Fedra (1991) identifies two general levels of hydrologic

model linkage with a GIS. In the first level of linkage, models merely read input from GIS files and produce output that can be displayed with the GIS. This usually involves little software modification and only requires adaptation of file formats and of input and output routines. The next level of linkage identified involves the sharing of files among several separate hydrological analysis components through the creation of a common interface.

The potential for using GIS in real-time flood control systems has been recognized by various government agencies and offices. At the time of literature review, a flood control system that includes the use of GIS had been described but not yet implemented by county personnel of Jefferson Parish, LA (Thompson 1991, p 149). This flood control system is proposed for reservoir control in periods of potential flooding, as well as for emergency preparedness and remedial action. The stated goal of this project is to provide "easy access to highly accurate spatial information" that can also be graphically displayed. Note that the accuracy of information produced by an emergency response system depends on the quality of the data input in addition to the modeling and data manipulation techniques themselves. Studies that test the accuracy of GIS-techniques and GIS-produced information remain scarce.

The U.S. Army Engineer District, New Orleans used GIS techniques to study flood protection alternatives as they relate to hydrologic, environmental, and socio-economic impacts to a study area (Ratcliff and Cunningham 1991, pp 87-89). While this project is innovative in its use of GIS and satellite imagery for floodplain management, it does not require real-time information and thus not the same degree of integration as a true emergency response system. Depodesta et al. (1991) outline the development of an interface between HEC-2 and GIS for floodplain management, which they suggest will eventually include real-time flood forecasting. The Regional Flood Control District of Clark County, NY is implementing GIS to support planning and engineering functions (Purves 1991, p 328). They have assessed the requirements of using GIS to support flood control planning, and imply that the operation of an Advanced Flood Warning System using GIS is desired.

The Fort Worth District of USACE has extensively investigated and evaluated methods by which GIS can be integrated into water and land resource planning (USACE Fort Worth District 1991). Among their specific study objectives was the automation of computer links between GIS and the HEC-1 hydrologic model and the HEC-2 hydraulic model for assessing the benefits of a flood control project. Although their study was not geared toward real-time flood prediction and assessment, the automated flood damage analysis methods they developed are of potential benefit to real-time flood prediction systems.

The Federal Emergency Management Agency (FEMA) has also considered coupling the HEC-1 and HEC-2 modeling programs with GIS. Daniel Cotter, of the Federal Insurance Administration of FEMA, has stated that the goal is to link automated data collection techniques and GIS technology with computer-based flood simulation packages to provide an efficient, automated process for developing FIS (Flood Insurance Studies) and FIRMs (Flood Insurance Rate Maps) (Cotter 1989, p 85). While the creation of flood hazard maps does not require real-time data processing, this type of automated technology may potentially be applied to FEMA's and other agencies' emergency management systems. It has indeed been stated that the Integrated Emergency Management Information System (IEMIS) being developed by FEMA is intended to combine GIS capabilities with analytical models for the analysis of natural and technological hazards and to provide an interactive computer system for emergency managers.

Despite the fact that rapid spatial assessment of floods has been identified as valuable for effective flood response, documented flood response systems still mainly provide point channel discharges or water surface elevations to emergency personnel. The comprehensive linkage of GIS to such systems is still in the developmental stage. It has been suggested that rather than investing solely in solutions that shorten response time or waiting for technological solutions that increase forecast lead time, that a more cost-effective alternative would be to develop analytic models that help decisionmakers better use forecast information (Krzysztofowicz and Davis 1984, p 11). The development of advanced user interfaces that provide decision support and procedural support as well as a link to GIS and computerized models are needed to help the decisionmaker make the optimal emergency response.

System Integration Using Graphical User Interfaces (GUI)

To address the use of multiple models and users with varied computing and technical abilities, a user interface shell linking the models within a unified user environment may be developed. A GUI can permit the use of multiple software components needed for a system task while leaving the user free to concentrate on the task rather than on operations of the system design (Brown 1988, p 4). Implementing a graphical user interface (GUI) is a particularly effective way to improve user understanding of a task (Powell 1990).

In an article on modeling and computer simulation in disaster response, McCoy (1983, p 43) states that "the ultimate goal of the computer simulation for emergencies is to enable emergency managers to maximize the use of information and resources so as to reduce the impact of a disaster on their communities." Successful transfer of

information between the computer system and the user is critical in meeting this goal. A GUI can improve information transfer between the computer system and the user by making the system and its components less confusing to use, providing procedural guidance that reduces the time of system operation, and by providing information in a variety of forms, such as text, graphs, and maps.

Frysinger (1993) states that the goal of environmental decision support systems (EDSS) that use multiple technologies to assist complex management decisions is "to make information available to humans in a form which maximizes the effectiveness of their cognitive decision process." A GUI can help the translation of conventional model output into information known to be directly useful for decisionmaking. It can facilitate the quick input and retrieval of relevant information and prevent distraction from unnecessary information. Thimbleby (1993) points out that not only does an interface augment a system (increases its speed, quality, and complexity of analysis), but it can also empower the user to perform new forms of analysis based on the additional information generated.

In addition to benefiting the end user, the development of a GUI that links existing computer technology may improve efficiency during the system development stage. Djokic (1993) makes a case for creating interfaces that unify existing GIS, expert system, numerical modeling, and utility software into systems for support of complex decisions based on some kind of spatially distributed system. These justifications for the development of interfaces include the fact that energy does not have to be spent customizing existing code or writing new code for each specific task. The system developer may concentrate on developing the system application rather than the computer environment.

3 Methodology

Interface Analysis

The success of a user interface in providing procedural support and improving information transfer, depends on thoughtful interface analysis and design. Current literature documents the general steps for successful interface analysis and design. The following paragraphs are based on Sutcliffe's (1988) description of the essential steps: analysis of user characteristics, task analysis, recording of user perceptions and terminology, and synthesis of this information within the constraints of hardware and software.

The objective of user analysis is to obtain knowledge of the skills and experience of potential users to predict what type of interface design they will find useful and easy to operate. Users with little experience with system components or with computers in general or who will have frequent or long gaps in interface use, will require additional help facilities and prompting and a more explicit interface presentation.

Task analysis is used to discover the required functions and operational sequence of a system. Identification of the desired system output is also an essential part of task analysis. Tasks are divided into those done by the computer, which include repetitive tasks such as calculations and data handling, those done by the user, such as judgments and heuristic reasoning, and those shared by the computer and the user, such as data entry, data retrieval, and decision support. (Those tasks shared by the computer and user will be explicitly represented in the interface.) Computer tasks do not need to be apparent to the user.

Recording tasks in terms of user perceptions and terminology is critical for the creation of an interface that provides effective procedural support. The names people use for objects and functions in the system, the connections made between tasks, and the visual and verbal metaphors used to describe tasks may be incorporated into the designer's conceptual model of the system (Sutcliff 1988). Literature on the development of user interfaces often describes "the user model" as the user's mental model of a system. The designer's idea of what this mental model is becomes the conceptual model for the interface design.

Sutcliff describes several types of user models, including theoretical cognitive models: (1) models of user knowledge, constructed to understand how users learn and which describe users knowledge in terms of plans and procedures, (2) models of user characteristics, which classify users in terms of skills and ability, (3) user task models, which reflect how much users know about the system in terms of its operation and expectations of how it will work, and finally, (3) user views, which present system components in terms of visual metaphors or verbal classification of meaning to the potential users. The more an interface conforms to users' preconceived notions of how it should appear and operate, assuming that these notions are accurate, the easier it will be to learn and less stressful to use. Task models and user views, in addition to user characteristics, are described as being of the most direct relevance to standard interface design and have been used as the conceptual basis of interface design for this project. The availability and capabilities of software and hardware will determine what type of interface can be designed to meet user needs and support the required tasks.

Interface Standards

Measures of good interface design are commonly cited in literature on computer interfaces. Brown (1988, p 21) defines general concepts for human-computer interface development that may be used as standards for interface design. These include the minimization of mental processing requirements, the efficient allocation of functions between the user and computer, the support of a user's mental model for the system, and making the interface easy to learn, easy to use, and functional. It is also important that a GUI, particularly one developed for decision support, improve information transfer between the user and the computer by directly reflecting the decisionmaking process in its procedural structure and by providing direct and reliable access to the information essential for decisionmaking. Superfluous distracting information is eliminated, and needed information displayed in an easily interpreted format. While it is important to consider how visual information can be displayed to *optimize* its use to the observer, discussion of the theory of human cognition as it relates to computer graphics is beyond the defined scope of this study. The following paragraphs discuss standards of interface design in more detail, based on the definitions by Brown.

Brown (1988, pp 6-7) suggests that, for an interface to be a useful tool, it must reduce the number of mental processing operations required for its use. Mental processing operations are defined as requirements for the user to learn complex commands and syntax, memorize encrypted code or formats, and translate data into units or formats before they can be applied to the problem.

The number of menial tasks done by the user should be reduced. Functions best done by the computer include the storage and recall of large amounts of data and the processing of data using prespecified procedures, while functions best done by humans include monitoring, serving as decisionmaker, and responding to unexpected events. The user should not have to commit commands necessary to perform a task to memory, but rather should be able to choose from a list of options.

The development of an accurate mental model of the system may be promoted by designing the static structure of the interface to reflect the procedural sequence of activity, and using descriptive labels to identify operations within the system (Powell 1990, pp 35-72). Consistent interactions between the user and the system are necessary if the user is to build an understanding of system operation (Scheinderman 1987). Brown states that a measure of the ease of learning is the extent to which a user may become proficient with minimal training and that a measure of ease of use is the extent to which tasks may be performed with minimal effort.

4 System Development

The Application

The Readiness Management System (RMS) under development by the Omaha District of the Corps of Engineers is intended to improve the response time to flood emergencies through accelerated generation, retrieval, graphic representation, and assessment of flood data. Important to the implementation of this system is the development of an interface linking the various modeling and GIS components required for flood prediction and providing procedural support to the users. By clearly directing the sequence of system execution, the interface may guide planning staff through the steps of emergency flood simulation, and by linking the system to the spatial analysis and graphic presentation capabilities of a GIS, provide flood prediction results in a format that aids rapid impact assessment and subsequently decisionmaking.

The RMS prototype was developed for the portion of the Missouri River stretching from the Oahe Dam at Pierre, SD to Big Bend Dam at Fort Thompson, SD. Impact assessment activity concentrates on Pierre and the nearby rural regions.

The methodology outlined in Chapter 3 will be used as the framework for discussion of interface development. User characteristics are first described, followed by task analysis, user perceptions, and system requirements. The information gained through interface analysis was used as the basis for interface development, the results of which are described in the proceeding chapter. Information was obtained through interviews with members of the RMS development staff.

User Analysis

The goal of user analysis is to identify the potential users of RMS, their likely expertise, the probable length and frequency of training, and the frequency of use of the system. Rather than being developed for analysts, the system is intended to help decisionmakers coordinate the flood prediction and analysis tasks of staff members. The ultimate users were Corps of Engineers district and division decisionmakers with varying levels of training in the system components. Familiarity with GIS and computers in general may vary widely as well.

Training on the system cannot alone ensure a system that the users understand. There are often gaps of months or years in the use of an emergency readiness system. Without continual use, users may forget their system training. In addition, providing extensive training to the current staff is of questionable value because of the uncertainty about who will actually be available to operate the system during an emergency. It was concluded that the system should be operable by a user with minimal training on the system. The interface should be highly "user friendly" (i.e., one that carefully directs the user through the prediction and assessment process). The interface is not intended to replace the need for hydrologic or hydraulic modeling expertise. Those models that require real-time calibration must still be managed by those with hydrologic expertise. The GUI provides the decisionmaker an opportunity to coordinate staff activities for real-time production of information useful for decisionmaking.

Task Analysis

Task analysis as described in Chapter 3 was undertaken to determine system functions, operational sequence, software components, and data requirements. It was also important to analyze the decision process itself to characterize the interface in terms of the information needs of the decisionmaker. Task analysis was originally conducted by phone interview with one of the Omaha District decisionmakers. In follow-up to this conversation, a chart showing basic modeling components, data inputs, and data outputs was provided. Through analysis of this chart, tasks were allocated to either the user, the computer, the user and the computer, or the technician working "outside" the interface. Data were identified as either that to be input by the user through the interface or that which could be accessed by the computer "behind the scenes." Real-time data were categorized as those that could be input by the user based on readily available information, such as gage reports or desired reservoir operation scenarios, and those that required preparation by specialists familiar with individual models. This information was important in deciding how the flood prediction and assessment process could be automated and directed by the interface to make efficient use of the time of staff technicians and decisionmakers alike. While data needs were not specifically outlined in the RMS function chart, the "GIS User Information Requirements" developed by the Headquarters U.S. Army Corps of Engineers (HQUSACE) Study Group for Emergency Management Use of EIS/GIS (EMIS-SDTG) (1992) were chosen by Omaha to be a basis for determining information needs.

Three main RMS tasks were identified: flood prediction, flood assessment (both in Figure 1), and graphical display. Flood prediction has the most defined sequence of

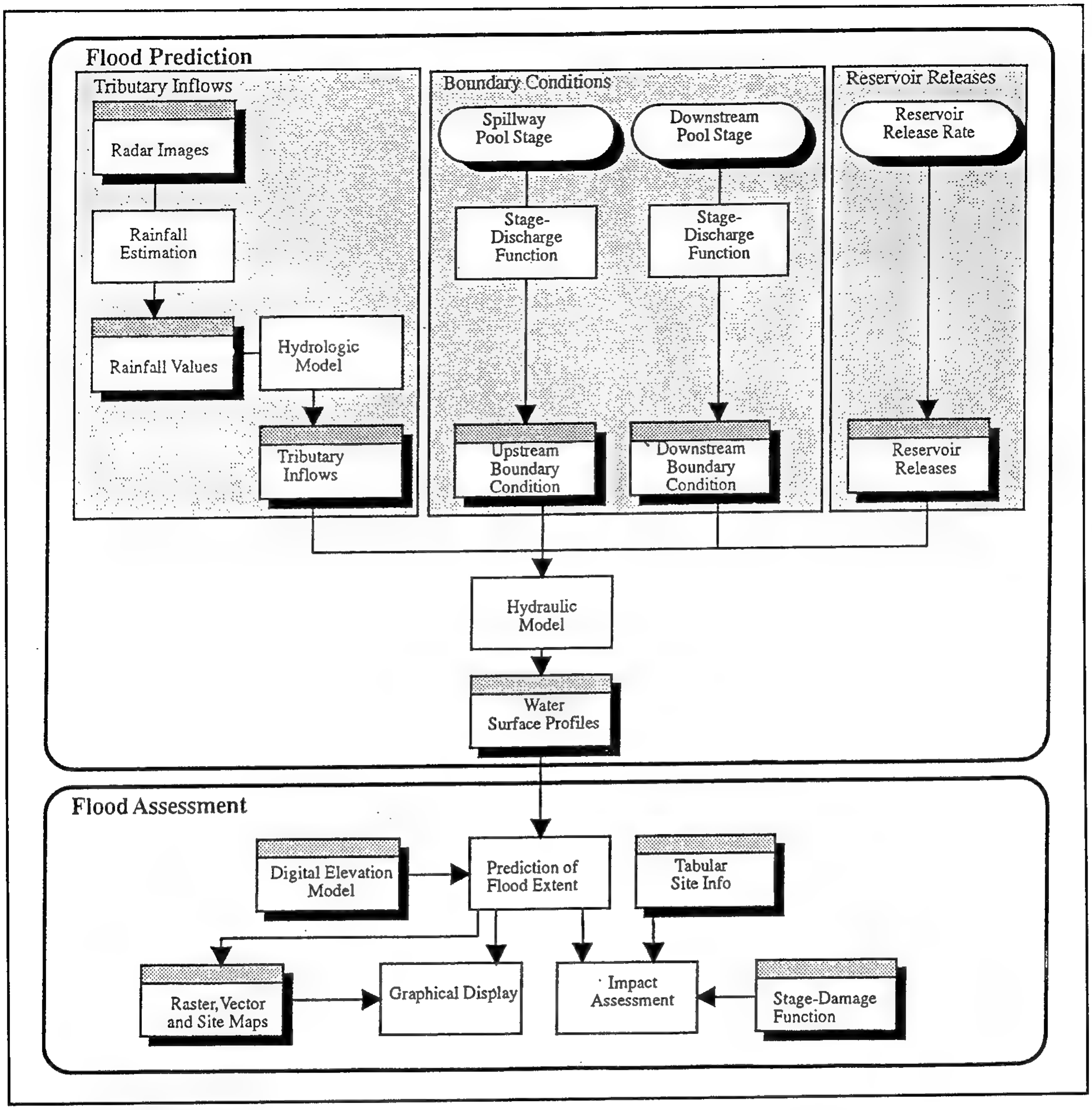

Figure 1. RMS functional flow chart.

operation. It must precede flood assessment unless the results of a previous simulation are being used. The sequence begins with the calculation of precipitation values by the U.S. Army Waterways Experiment Station (USAWES) rainfall prediction software, using National Weather Service ground-based radar data input (Fischenich 1991) (Figure 1, upper left). The predicted precipitation values are stored in Hydrologic Engineering Center's (HEC's) Data Storage System (DSS) format for subsequent use by the HEC-1F stream flow forecasting program (represented in Figure 1 at "Hydrologic Model"). The HEC-1F program is used in two stages, one for parameter estimation and one for precipitation-runoff simulation. Parameter estimation is performed first using an "emodel" input file. During this stage, the program accesses the predicted precipitation values previously stored in DSS format.

Output is also stored within a DSS file. Two hydrographs, two loss rates, and two base flow parameters must be encoded in the emodel file *at the time of forecast*. An existing text input file for HEC-1F, based on previous model calibration, may be directly edited by the hydrologist to include these parameters or by using the HEC-1F preprocessor program, PREFOR, which fills in selected input. Real-time application of the calibrated model is required to allow additional modification and fine tuning of parameters for real-time modeling (USACE 1989, p 23). HEC-1F is then run with the fmodel input file. The subbasin hydrographs generated from the emodel stage as well as *observed* hydrographs are accessed from DSS files. A peak discharge value for the outlet of the Bad River tributary is extracted from HEC-1F fmodel output for subsequent addition to the discharge values used in the HEC-2 input file. It is assumed that the peak discharge for the tributary occurs at the same time as the peak for the Missouri. This may be unlikely, and represents a worst-case scenario.

The HEC-2 Water Surface Profiles program ("Hydraulic Model" in Figure 1) is used to generate water surface elevations at channel cross-sections (USACE 1990b). Upstream and downstream boundary conditions and reservoir releases can be input into a pre-existing HEC-2 input file. This input file is also used to describe channel geometry and reach length. The downstream pool stage is input as the starting water surface elevation. Upstream boundary conditions are input as a spillway discharge value at the cross-section corresponding to the spillway location. Reservoir release is input as a discharge value at the final upstream cross-section location. The HEC-2 output files may provide, among other information, water surface elevations for channel cross-sections defined in the HEC-2 input file. A GRASS f-tools program, f.input, extracts water surface elevations from the HEC-2 output file for every cross-section that corresponds to the required vector cross-section map (Betancourt 1992). Another GRASS program, f.wsurf, interpolates these elevation values into a water surface map, which it then overlays with a digital elevation model (DEM) to create a flood depth map. The actions provided by the f-tools programs are shown in Figure 1, at "Water Surface Profiles."

The RMS flood assessment process (bottom of Figure 1) was not as well-defined by the user during the task analysis process. Consequently, the GIS User Information Requirements previously mentioned were chosen as a guide for the type of analysis and information that should be included within the interface. The post-disaster information categories include land areas affected, facility damage, public and private utility damage, transportation/infrastructure damage, hazardous/toxic materials facility damage, flood control damage, and communication system damage. The basic output needs were identified as maps of flood depth and extent that could be spatially assessed in conjunction with geographic, demographic, and economic data.

It is possible that some decisionmakers would like to explore flood information in a specific sequence, perhaps one that reflects a particular decisionmaking process. This was not defined by the task analysis for RMS. Ideally, a decision-support system would not only provide useful information, but allow alternative decisions to be generated and compared based on a combination of different values.

In addition to the specific tasks required by RMS, the interface must support secondary tasks, such as file editing, status reports, and the extraction of system help. Interface "devices" for user input and graphic display must be incorporated to support these tasks.

User Perceptions and Terminology

The system diagram provided by the Omaha District technical staff communicated the user's perception of the sequence of tasks. The system was depicted as a collection of modeling and data objects. This chart revealed the terminology used by engineers familiar with hydrologic and hydraulic modeling software and other modeling and GIS technology. Because it is possible that the ultimate user (the decisionmaker) will not be familiar with all the specific software chosen and because individual software components could eventually be replaced with different or updated technology, general terms for the system tasks were sought to replace the names of the actual software or model in use. Omaha staff responded positively to the concept of using terms that reflected system function rather than specific software names and suggested some substitute terms they felt to be even more appropriate.

System Requirements

Omaha District chose to use existing computer technology rather than write new code for each specific task. A benefit of this is the ability to redirect energy and resources from the development of the computer environment to the development of the application itself. Another benefit is that the capabilities, limitations, and assumptions of existing technology are more likely to already be documented. Each chosen component is public-domain, which translates to accessibility (but not necessarily to consistent and continous software support). Where a common database does not exist between the components, flat text files are used as intermediate files to bridge data flow between models. Shell scripts are used as command bridges between the components.

Rainfall Estimation

Precipitation tracking and forecasting software developed at USAWES was chosen for incorporation in RMS (Engdahl, Bae, and Georgakakos 1991, pp 405-409). This software uses National Weather Service (NWS) ground based radar data as it is produced and converts it into spatially distributed rainfall totals. This prototype software is intended to produce precipitation data for input to existing lumped parameter hydrologic models. As the quality of radar data images and the understanding of the spatial structure of storms improves, it is possible that precipitation data may be created for input to spatially distributed models. The prototype software used in the RMS demonstration is being replaced by a new phase of software that will directly use the high quality NEXRAD data produced by the NWS and output data to the HEC-DSS data storage system (USACE 1990b). Precipitation values may be subsequently extracted from DSS for input into HEC modeling software, such as the HEC-1F Flood Hydrograph software.

Hydrologic Modeling

A hydrologic modeling component was incorporated into RMS to provide short-term forecasts of the unregulated inflow of tributaries to the Missouri River. The chosen HEC-1F modeling software, developed at the Hydrologic Engineering Center (HEC), is designed for use in real-time flood forecasting and flood control operations (USACE 1989, p iii). It is a special version of the HEC-1 Flood Hydrograph package, a lumped parameter hydrologic model that simulates the surface runoff response of a river basin to precipitation by representing the basin as an interconnected system of hydrologic and hydraulic components (USACE 1990a). The two main capabilities of HEC-1 used by HEC-1F are parameter estimation and precipitation-runoff simulation using unit hydrograph and hydrologic routing procedures (USACE 1989, p 3). Parameter estimation is used to estimate runoff parameters, such as loss rate, unit hydrograph, and base flow, in real time. Precipitation forecasts may be used to forecast runoff. This program and other HEC programs were chosen by Omaha district based on their "universal acceptance and the likelihood that they will be sanctioned by other organizations" (Fischenich 1991).

Hydraulic Modeling

A hydraulic modeling component is required within the system for generating water surface elevations at channel cross-sections. The HEC-2 Water Surface Profiles program was chosen for the initial RMS prototype. This well-established program calculates water surface profiles for *steady* gradually varied flow in natural or man-made channels. For given flow values, HEC-2 will compute the water surface

elevation for specified cross-sections of interest. The effects of channel obstructions, such as bridges, culverts, and structures in the floodplain may be taken into account by the model. An advantage to using this modeling component is that a GIS program has been previously developed within GRASS that will translate this model's output into flood extent maps (USACE 1990b).

Omaha District has considered the future integration of UNET software as a substitute for the HEC-2 software. UNET modeling software is a one-dimensional *unsteady* flow program (USACE 1992). It incorporates equations that can account for levee failures and storage interactions. This capability would be of advantage to RMS because levee failures have a large impact on river hydraulics and thus predicted flood extent. Another advantage to using UNET is that it takes input directly from and provides output directly to the HEC-DSS database, which would simplify the link between HEC-1F and the hydraulic component. Currently no GRASS program translates UNET output into flood extent and depth maps, which has caused the present delay in linking UNET to the GUI.

Data Storage System

The HEC-DSS data storage system is used to store, retrieve, and display time-series data for both the rainfall estimation and hydrologic modeling components of RMS. Ideally a common database format would exist for the system that would allow each component to directly input and/or extract needed information. The use of multiple software components, however, often requires the integration of different databases. While HEC-1F and the precipitation estimation software are linked by HEC Database Storage System (DSS) database, HEC-2 is not. Flat text files were used to bridge data flow between HEC-1F and HEC-2. A GRASS program already exists to extract data from a HEC-2 ASCII output file and incorporate them into the GRASS data format.

DSS display programs exist for the display and tabulation of modeling results for review and comparison with observed data. DSS utility programs exist for the manipulation, editing, and analysis of results (USACE 1990b). It has been stated that DSS is much more efficient than conventional relational data bases for time series data (USACE 1992).

Geographic Information System

Spatial analysis functions are performed by GRASS (Westervelt et al. 1989). GRASS was developed by the U.S. Army Corps of Engineers Construction Engineering Research Laboratories (USACERL) as a public-domain raster-based GIS. Its use as a tool for environmental modeling is rapidly increasing and many public and private organizations are choosing to integrate it into their environmental planning and

research programs (Martin et al. 1989). Both the GRASS and ARC/INFO GIS (1991) are used by Omaha District for their RMS prototype. A prime reason Omaha District desired the development of a GRASS-based interface to the RMS prototype is the availability of GRASS in district offices. Although the RMS prototype was developed specifically for the Oahe Dam Safety Project, such a system could be adapted to other reservoirs managed by the Corps of Engineers.

Another reason for using GRASS is that its raster-based data structure is well-suited for the modeling and assessment of spatially distributed phenomena and impacts. The GRASS f-tools software generate flood depth and extent maps, which can be overlaid with other data layers to spatially assess impact. The fact that GRASS is public-domain is also beneficial to the RMS system. Because its code is open, it can be competitively adapted to suit a specific application. Updates and code contributed to GRASS may be obtained free of charge. The interface can be adapted as the contributed code expands the hydrologic modeling capabilities of GRASS.

GRASS is based on UNIX, a universal operating system, increasing the likelihood of its compatibility with other systems. The command line format of GRASS is conducive to interface design, as GRASS commands can be directly encoded within a custom interface, and GRASS macros can be created and used in real time.

Xgen Interface Generator Program

The public-domain Xgen software was used to generate the interface prototype. It is an object-oriented code generator that implements interfaces through X-windows using the Motif™ Toolkit (1993). Its basis on the widely used, public domain X-windows windowing environment provides cross-platform compatibility for the final interface and allows it to be remotely operated. This software was designed for the rapid generation of graphical user interfaces within existing shell level programs (Buehler and Poulsen 1989). Several of the capabilities of Xgen that make it useful for general interface design have been previously identified by Poulsen (1992, p 26). It is able to store parameters input by the interface user and execute shell level commands that use these input parameters. The output of individual modeling components may be captured within interface variables and fed to subsequently activated system components. Another useful feature is the ability to specify whether an interface command must be completed before continued system execution or whether system execution may proceed while the current task is completed. This is an especially important capability when task sequence is critical, such as for flood prediction.

Another advantage to using Xgen is that the Xgen script written by the interface programmer does not have to be compiled, and thus may be run immediately to test

program changes. The interface developer does not have to know and cannot use a high-level programming language to create the functioning interface.

Data

RMS operation depends on the pre-existence of certain data. A large portion of system implementation is the creation of the required database. By having the database already established, much time is saved and possible errors in data translation reduced. The user should have to provide only real-time data and judgments. Some real-time data may be collected directly by the computer system, such as radar images for rainfall estimation. Currently spillway discharge and downstream boundary conditions are input by the user. These could ultimately be collected by automatic gages. Reservoir releases are input as desired by the user to evaluate various release scenarios in relation to downstream impacts.

The pre-existing database would ideally be updated on a regular basis. For instance, landuse maps and topography maps need to be updated periodically to reflect development. HEC-1 and HEC-2 input files may also need to be updated to reflect land use changes or seasonally changing conditions. Flood events themselves cause changes that should be reflected in the input files. Policies for the update of such systems should be established, to ensure that the system is ready for emergency use.

Ideally, GRASS data layers that correspond closely with the information requirements established by EMIS-SDTG may be included in the database. The RMS prototype interface uses the GRASS site list format to store site information, such as phone number, addresses, and contacts. A database software package was *not* used to store additional site and tabular data. Table 1 describes the necessary data for the RMS system prototype defined in this document.

Table 1. Data requirements.

Software	Data Input	Format	Means of Input	Source
Rainfall Estimation	Radar VIP array	NWS	Automatic	Real-time
HEC-1F	Emodel input	Formatted ASCII file	Automatic	Pre-existing
	Precipitation values	DSS file	Automatic	Real-time
	Fmodel input	Formated ASCII file	Automatic	Pre-existing
HEC-2	Cross section geometry, reach lengths, direction of flow, loss coefficients	Formatted ASCII file	Automatic	Pre-existing
	Flow regime, loss coefficients	Numeric string	Automatic	Pre-existing, edited by expert user
	Tributary inflow	Numeric string	Automatically extracted from HEC-1F output	Real-time
	Spillway discharge	Numeric string	By the user	Real-time
	Reservoir discharge	Numeric string	By the user	Real-time
	Downstream pool stage	Numeric string	By the user	Real-time
GRASS f-tools	Water surface elevation	HEC-2 ASCII output	Automatic	Real-time
	Channel cross-sections	GRASS vector file	Automatic	Pre-existing
	Digital elevation model, 30 M resolution	GRASS raster file	Automatic	Pre-existing
Spatial Analysis Graphical Display	Flood depth and extent	GRASS raster file	Generated using f-tools	Real-time
	Area info. (i.e., land use, and population)	GRASS raster file	Selected by the user	Pre-existing
	Linear info. (i.e., political boundaries, roads, waterways, etc.)	GRASS vector file	Selected by the user	Pre-existing
	Site info. (i.e., hospitals, and schools)	GRASS site file	Selected by the user	Pre-existing

5 GUI Description and Evaluation

The visual and operational design of the prototype GUI may be evaluated in terms of the interface standards described in Chapter 3, as well as by its ability to support the project goals of providing procedural support and improved information transfer.

Organization

The interface layout was organized to include specific areas for primary task control, subsidiary task control, input, and graphic display (Figure 2). The specification of these areas is intended to provide consistency in user-interface interaction. They remain in place during the entire interface operation. Separate flood assessment and display control boards pop up in the primary task area when activated from the "permanent" RMS operation chart. By physically grouping associated interface functions that require similar action from the user and that provide similar response, the user can learn to expect certain reactions from the different areas of the interface and thus their mental model of the system and its functions will be strengthened. The primary task control area of the interface provides control of the three main tasks identified through task analysis: flood prediction, flood assessment, and display. The subsidiary task control area includes user support functions such as help and system status reporting, file editing, and system exiting. An attempt was made to avoid excess functionality, while at the same time providing additional functions for the more advanced user who may want to directly edit input files. The main tasks and the supporting tasks were kept separate to prevent confusion about the required main task sequence.

All help messages, prompts, user input, and file editing occurs in the input area. Items chosen through the graphic display task board are displayed in the display area. While display *content* is controlled in the primary task control area, manipulation of the display window itself, such as window zooming and erasing, is controlled within the display area.

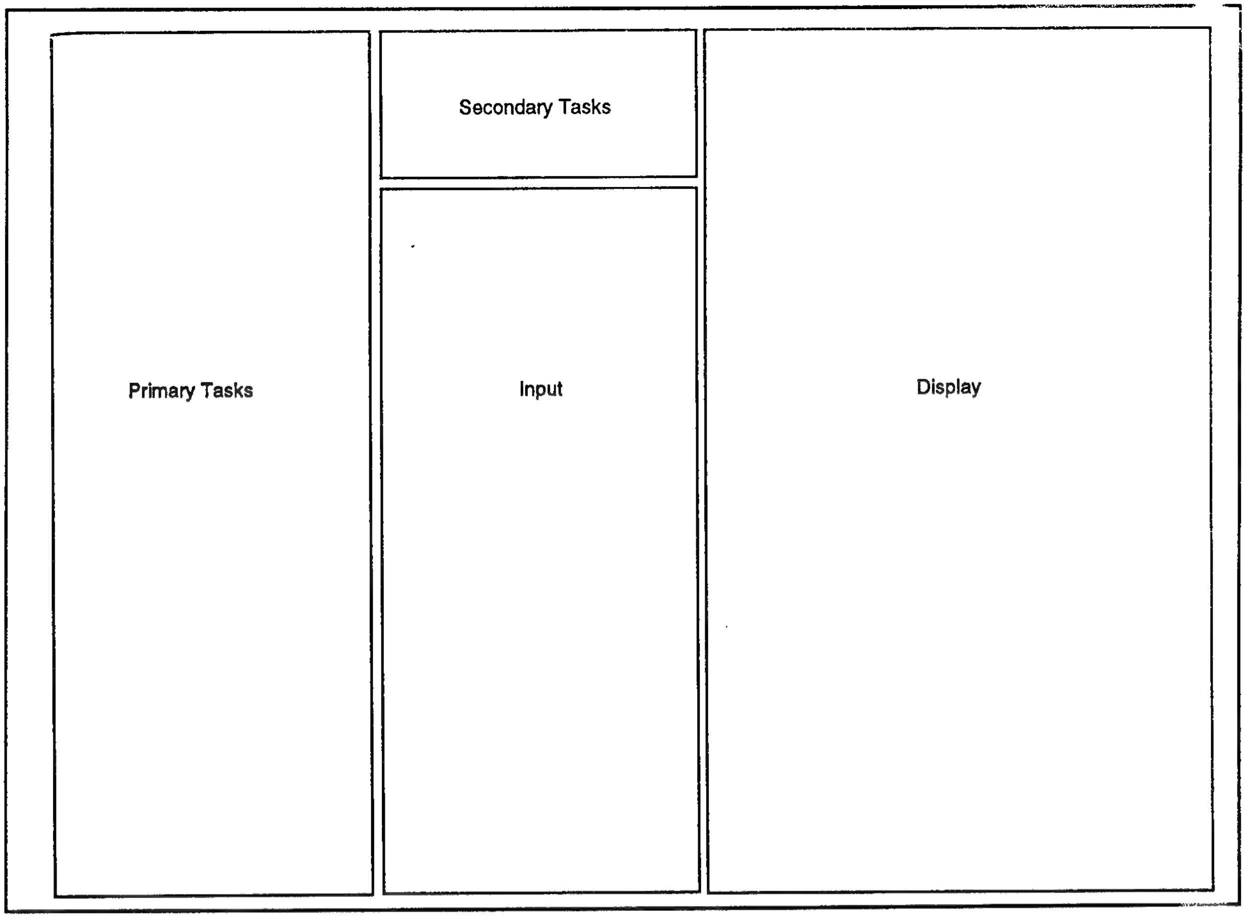

Figure 2. Interface layout.

System Presentation

Because there will be frequent and long gaps in system use, explicit guidance should be provided to the RMS user. A design goal was to simplify the sequence of tasks as much as possible and present them in terms meaningful to the user. As mentioned in Chapter 4, two trial designs for the primary task board were developed. One presented the flood prediction and assessment sequence as consecutive menus that allowed visual and physical access to functional buttons only as they were needed. Figures 3 and 4 show the first two interface menus of the design. This design was intended to focus the user on the task at hand, but still the the entire sequence was not visible; the user could not anticipate the next task and there were no visible reminders of completed tasks. The second design incorporated task buttons in a flow chart form, similar to the user's initial description of the system (Figure 5). Users preferred this explicit representation of the system framework and it was retained.

Powel (1991) recommends certain qualities of a GUI. The user should be visually directed to important information, screen text should be distinguishable from user text entries, and the user should be kept focused on the current task by the minimization

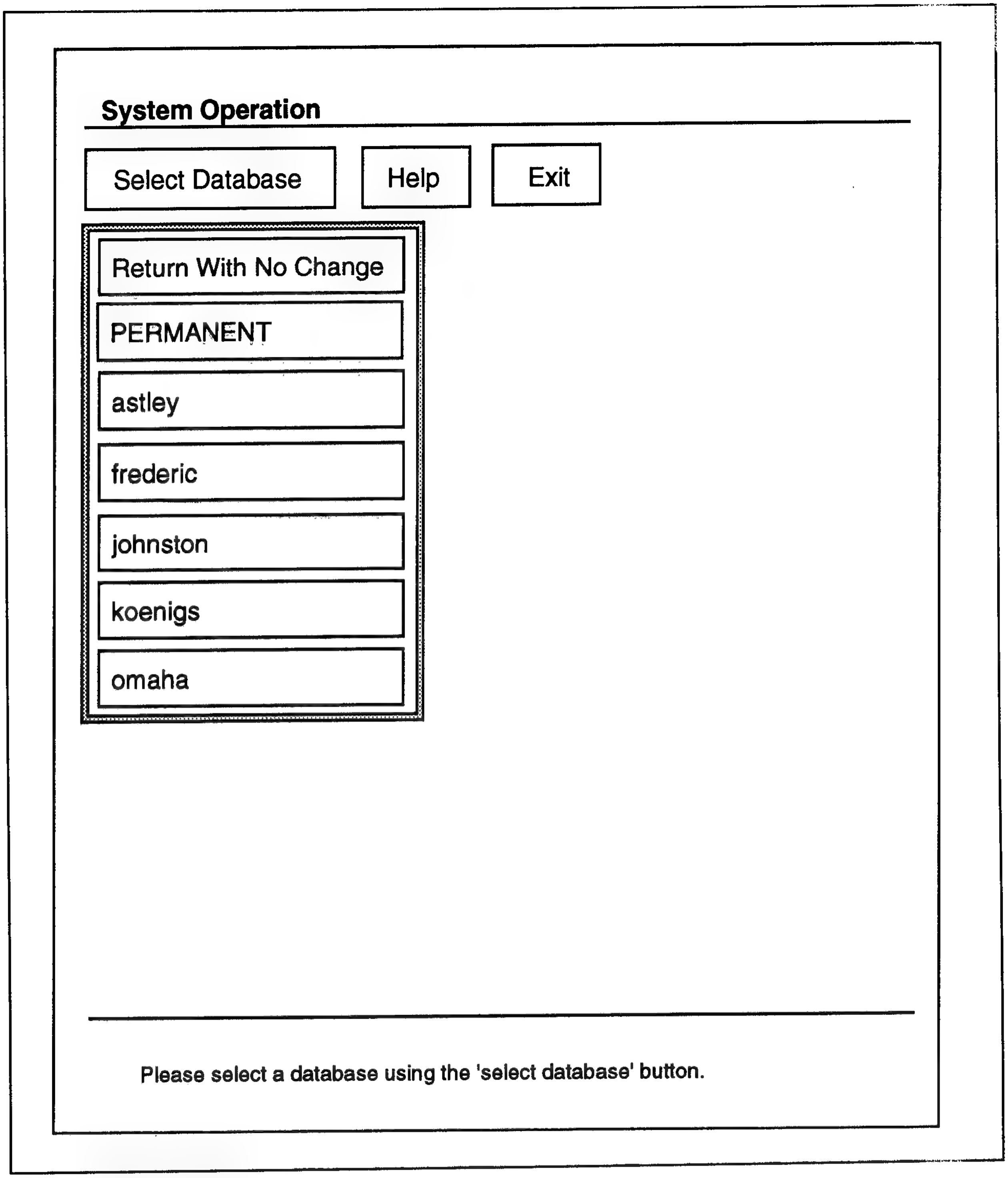

Figure 3. First interface menu.

of screen clutter. There is consistency of position, color, type, spacing, order, and capitalization, clarity and conciseness of terminology, and use of color to reinforce meaning. It is also desirable to reduce keystrokes, anticipate the user's next move, provide error messages that help solve problems, make short-cuts available, and use appropriate text and tone for error and warning messages.

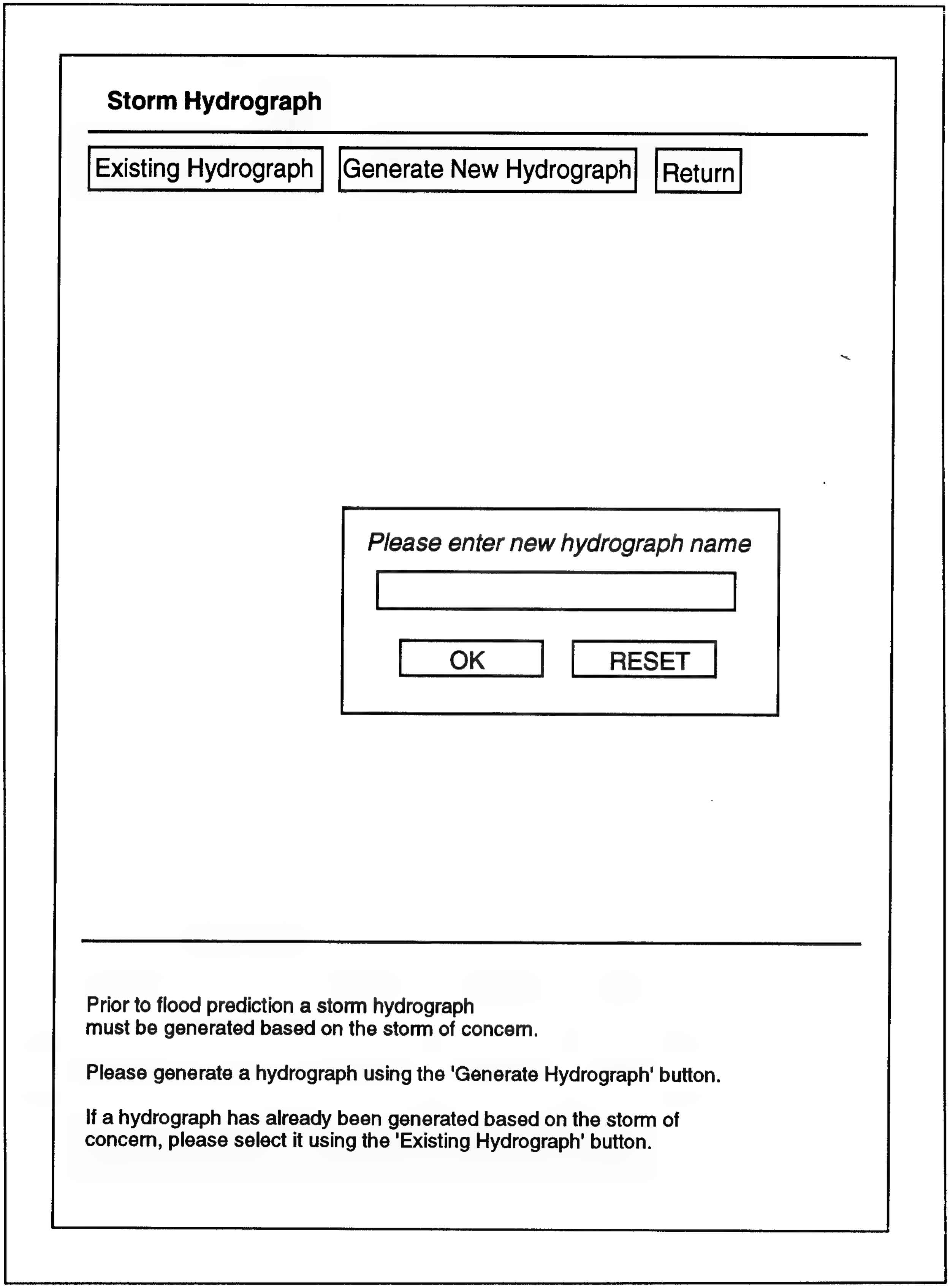

Figure 4. Second interface menu.

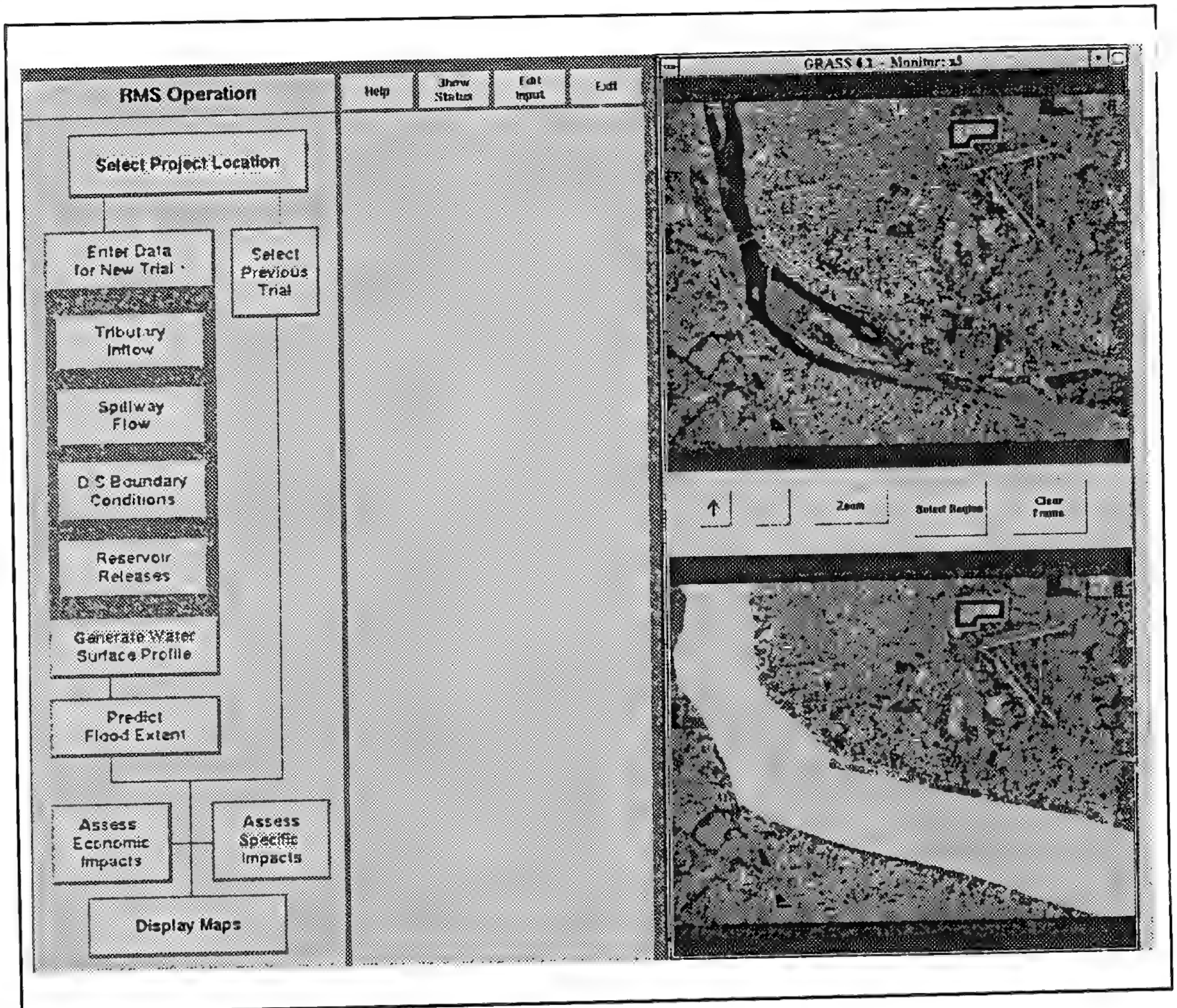

Figure 5. Task buttons incorporated into flowchart format.

The button labels incorporated into the GUI are specific action statements that describe the task activated by the button, such as "Generate Tributary Inflows" or "Predict Flood Extent" (Figure 6). This reinforces the user's conceptual understanding of the system and individual task requirements. These action statements do not reveal the specific software activated by the system, as the chosen software could conceptually be interchanged with other software products of similar capabilities. The button that activates the HEC-1F model is labeled "Model Tributary Inflows," rather than "Run HEC-1F." Labeling conventions were established for buttons of particular function classes, such as "OK" for input verification or "Return" for backtracking through the system. Each button in the operation chart is initially "grayed out" and may not be activated until the sufficient preceeding steps have been completed. Buttons become "active" or available for use when all of the preceding steps have been completed. Buttons darken when active to direct the user's actions and to show the user's place in the task sequence.

Interface colors were chosen to enhance procedural support, but were used conservatively to avoid creating a cluttered, distracting screen. It was decided that the color of the primary task or "action" buttons should contrast the most with the background interface color to attract the attention of the user to the primary tasks. Gray was chosen as the background interface color and light turquoise for the system task button. Turquoise was chosen because of the general convention that "green" colors symbolize action. Black letters stand out against the turquoise buttons. Permanent screen titles and secondary function buttons, such as "Status" and "Help," consist of black letters against the gray background, which does not immediately attract attention. Prompts for user input or file selection all appear in white letters against a blue background. This change in color format alerts the user that data input is required. The consistent use of color reinforces the user's expectations of the different interface components.

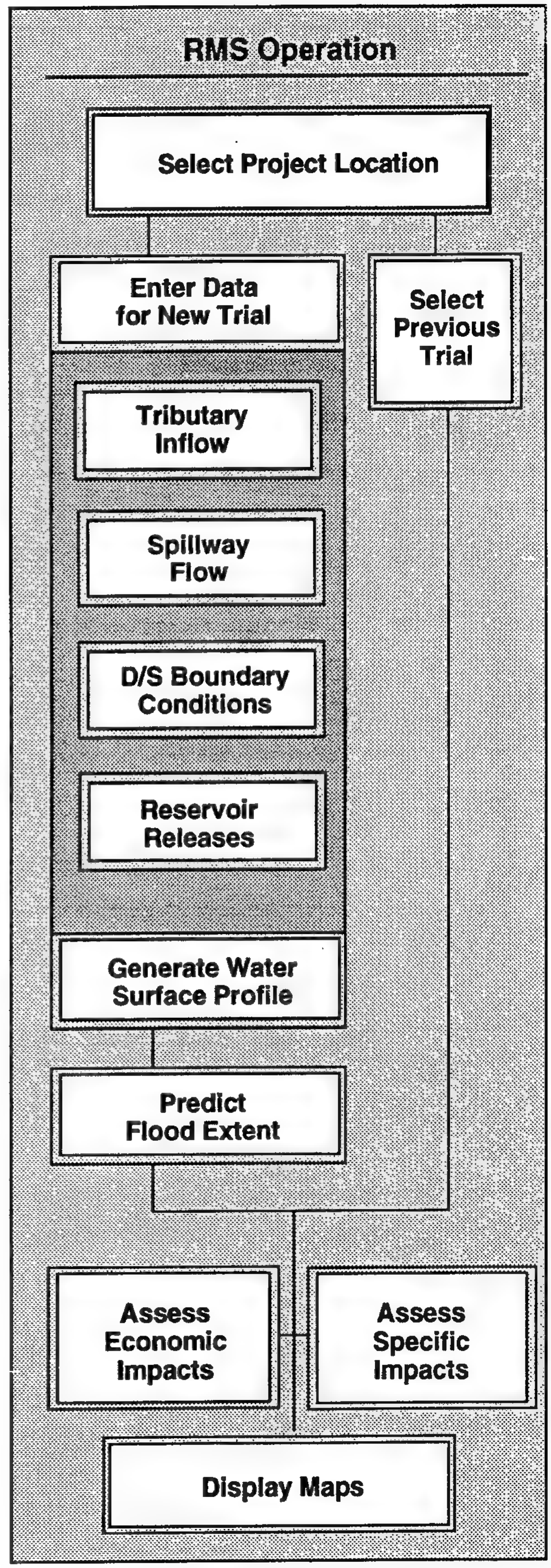

Figure 6. RMS operations chart.

GUI Operation

As noted in the system requirements section, Xgen runs on the UNIX operating system and requires the standard X-window environment. The interface is activated by simply typing "xgen <script.name>" after the UNIX prompt. This is the only direct interaction with UNIX required. All programs subsequently used are activated through interface buttons.

Procedural Support

The GUI is intended to aid the emergency decisionmaking process by providing the decisionmaker with the ability to quickly process information into an organized and accessible format. This goal is achieved by the development of an operation flowchart format for the interface structure. As noted earlier, the GUI operation flowchart (Figure 6) closely parallels the functional diagram of RMS (Figure 2). Each step within the chart is a user selectable button, which when activated prompts for needed parameters, inputs these into the appropriate model, executes the model, and then captures the output for subsequent input into the next component within the task sequence. By preprogramming buttons to activate support programs, the need for the user to memorize command syntax is reduced. This operations chart format was well-received by the user.

The first step within the operations chart “Select Location” prompts the user to select the mapset corresponding to the region of interest (Figure 7). The user must next indicate a wish to run a new simulation or assess previously modeled flood conditions by clicking either “Enter New Conditions” or “Select Default Flood” from the operations chart, respectively. If assessment of default flood conditions is chosen by the user, he/she is prompted to select a flood event and then allowed to proceed directly to impact assessment and map display by activating “Assess Economic Impacts,” “Assess Specific Impacts,” or “Display Maps.” If a new simulation is requested, the user is prompted to type in a name for the new trial (Figure 8). On entering this name, the new trial sequence begins.

The first four buttons in the trial sequence (Figure 6) create input for water surface profile generation. Activating the “Tributary Inflows” button prompts the user to select input files for runoff prediction (Figure 9). The expert user may edit input files prior to model run. Model calibration is not specifically supported by the interface. The user may input the rainfall data (Figure 10), although this step is not required since the interface is designed to automatically extract precipitation values from DSS files. During interface testing, precipitation values were extracted from sample DSS

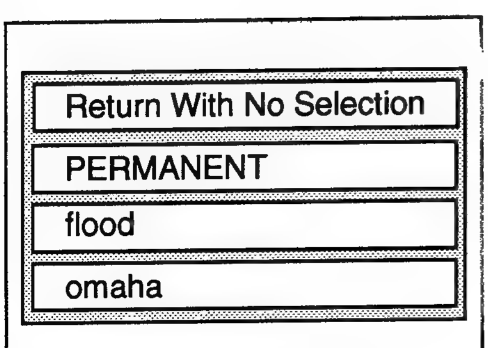

Figure 7. Prompt to select mapset.

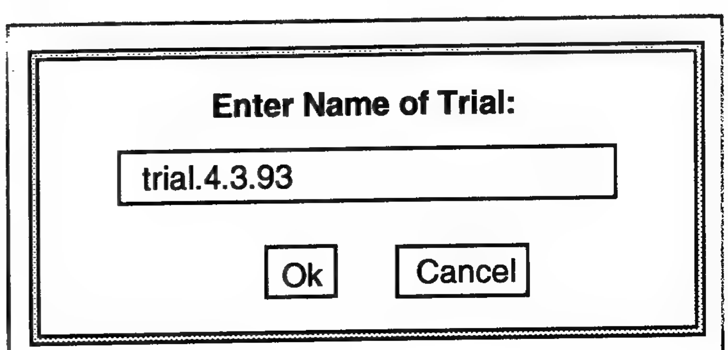

Figure 8. Prompt for trial name.

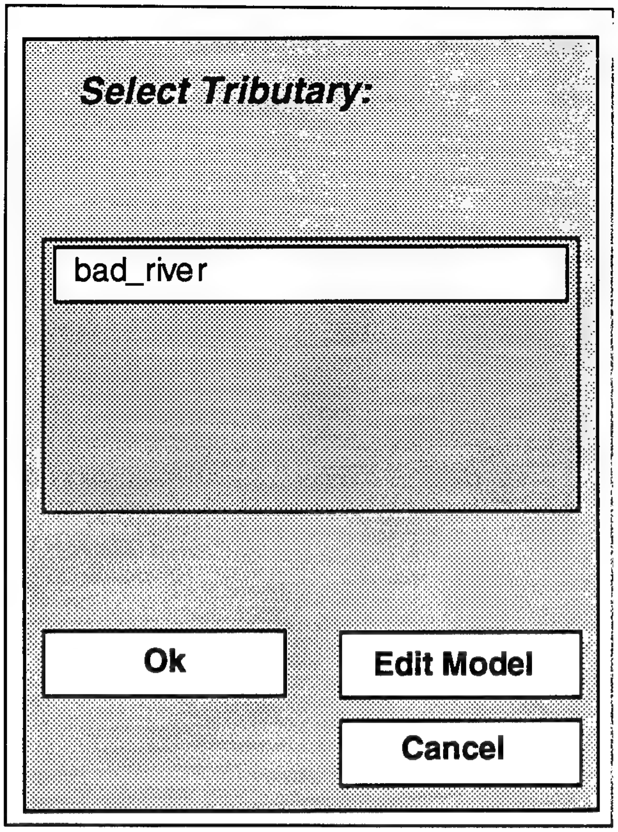

Figure 9. Prompt to select tributary.

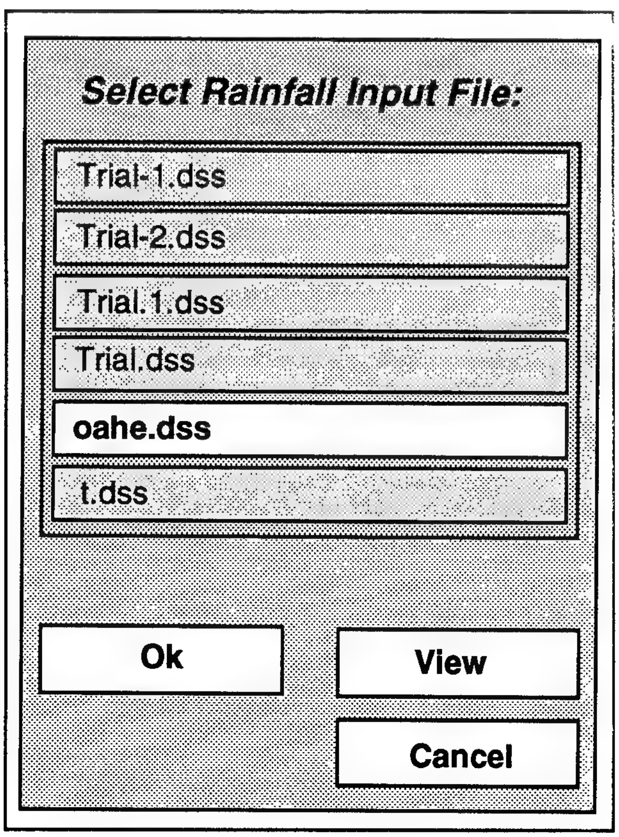

Figure 10. Prompt to select rainfall data.

files previously generated by Omaha District with the WES rainfall prediction software using fabricated radar images. Modeling tributary inflow is activated on file selection.

"Spillway Flow" (Figure 11) prompts for spillway discharge entry, obtained by telephone from reservoir personnel, or by automatic gages. Pressing "D/S Boundary Conditions" prompts for input-gaged pool elevation at Big Bend Dam (Figure 12). The input of reservoir release is the last task of the four-button sequence to be completed before calculating water surface profiles. A click on "Reservoir Release" brings a prompt to enter a reservoir release rate (Figure 13). Previously generated tributary inflow, spillway flow, downstream pool stage, and the specified reservoir release rate are input to the hydraulic model input file on activating "Generate Water Surface Profiles," and the hydraulic modeling program is run. When the water surface profile generation is complete, model output is captured in an on-screen editor to allow the user to verify that water surface profile was generated successfully before invoking map creation, itself a lengthy interpolation process (Figure 14). Interpolated flood surface and flood depth maps are generated by clicking "Predict Flood Extent." The separate buttons for these two functions gives intermediate system feedback, which outweighs the cost of the extra step.

The operations chart guides the user quickly through the prediction and assessment process by limiting the actions

to be performed at each step. In an emergency management system, the user must not perform functions out of the required sequence or be trapped while exploring system functions. However, the chart layout does allow the system to run repetitively once values have been entered for all required parameters. In addition to allowing repetitive runs to test different reservoir release scenarios, it allows the user to "back up" and change input, thus prevents a need to restart the process in case of an error or change in input.

An associated feature is the status button (Figure 15), which provides the user with a record of the previous input. If the user is called away from the terminal, upon return the status button may be used to check the parameters which had been previously entered or to confirm the step last completed. For example, if the user was called away from the terminal prior to water surface profile generation, on return the user could check the values entered for upstream and downstream boundary conditions to confirm whether or not they were consistent with any new information that had come in. The status button may also be used to determine parameters that were input during previous system runs. This removes the menial task of remembering previous

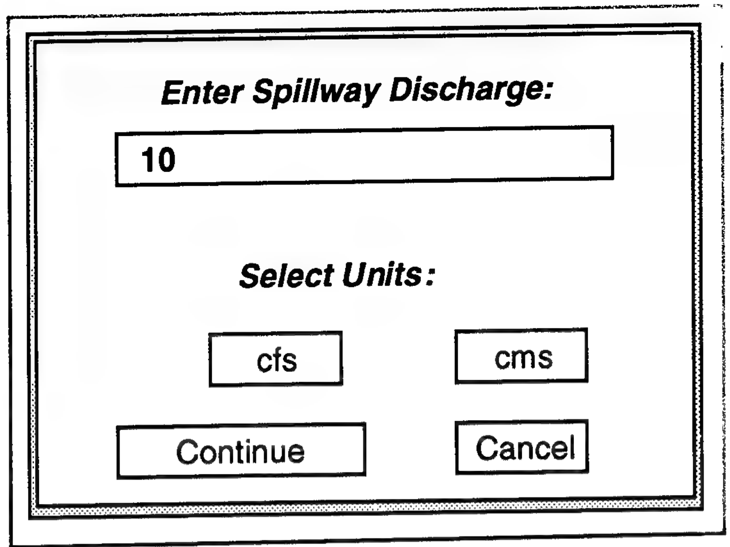

Figure 11. Prompt to input spillway discharge.

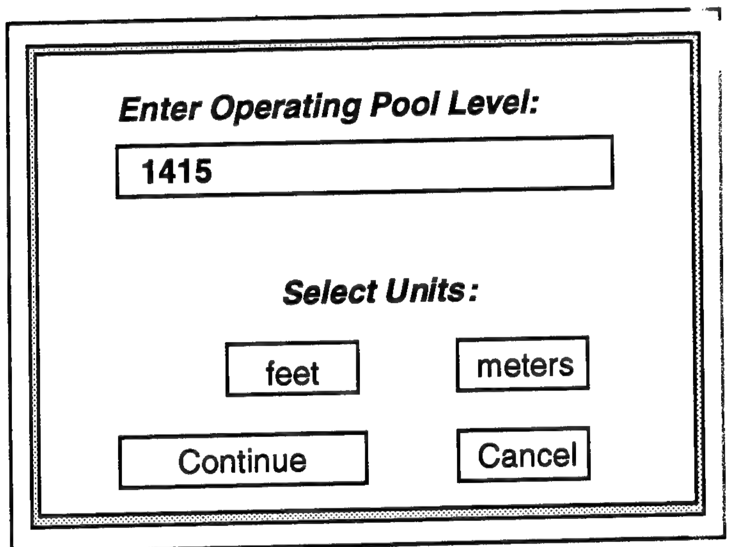

Figure 12. Prompt to downstream pool stage.

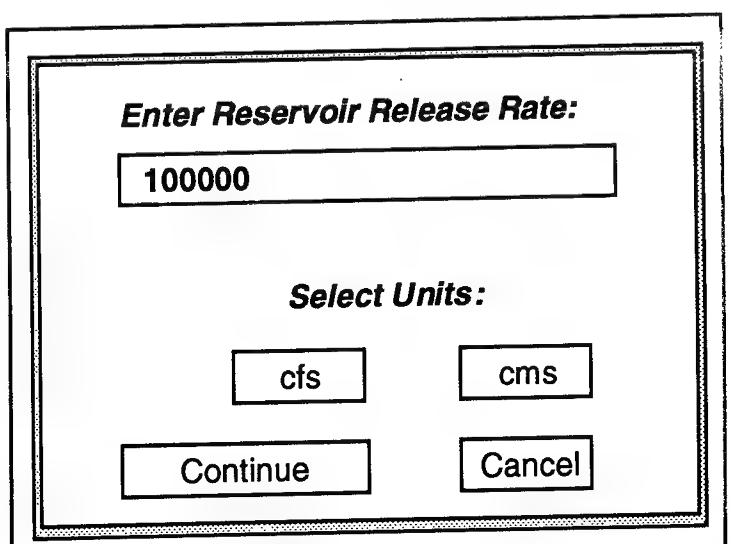

Figure 13. Prompt to reservoir release.

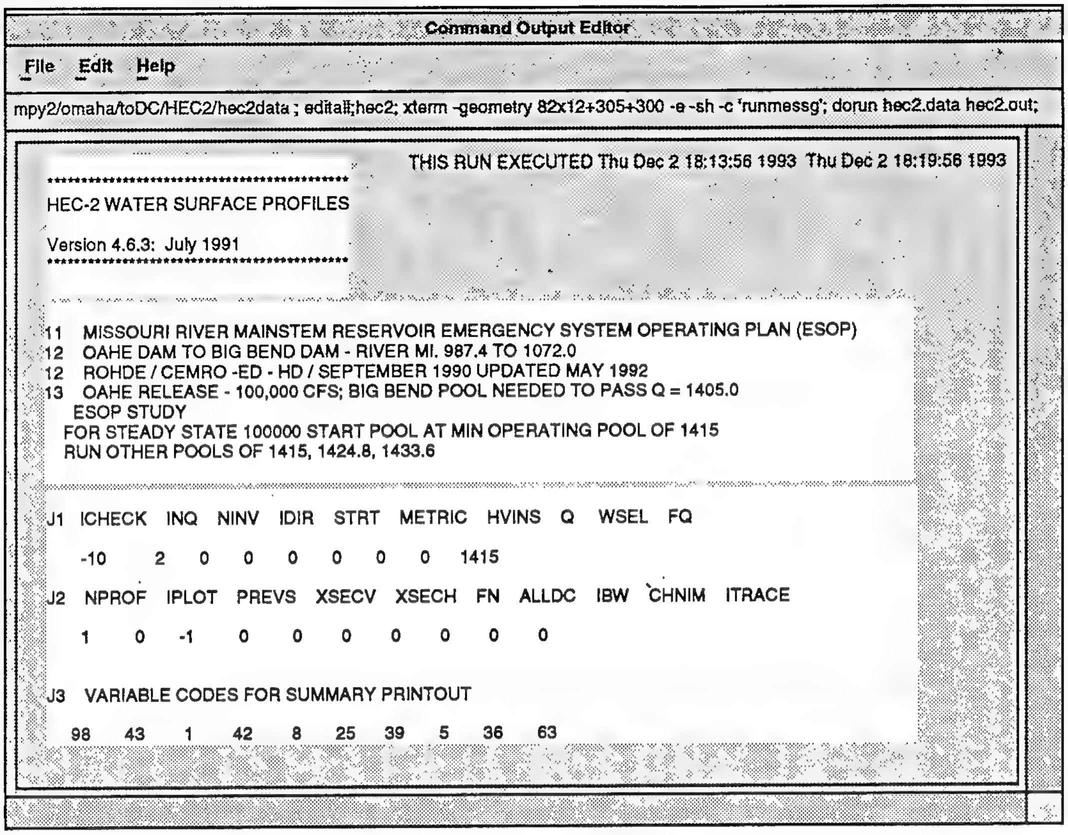

Figure 14. Water surface profile generation output file.

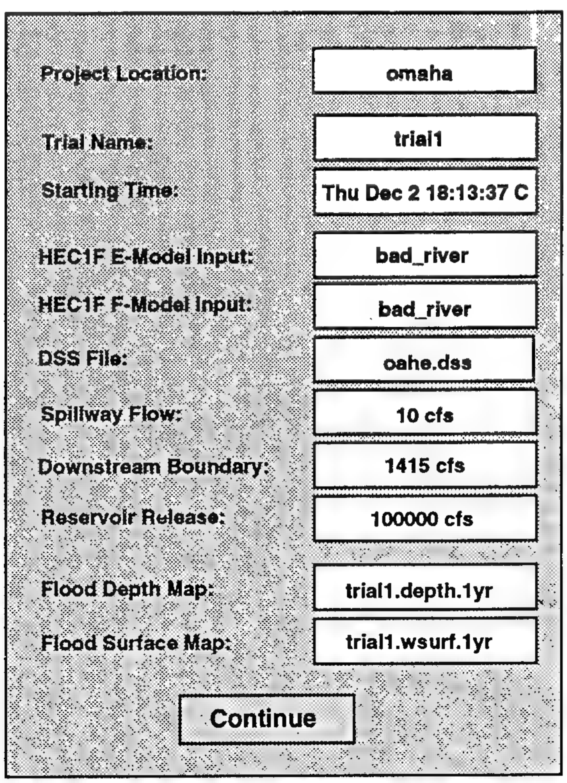

Figure 15. Status report.

input from the user and reassigns it to the computer.

Subsidiary task buttons are included for activities outside the normal flood prediction and assessment sequence (Figure 16). Information about the system and its operation is constantly available to the user through this selection. Several levels of help are provided. A general help button is provided, which explains the basic functions of the interface. Context-dependent help on each specific procedure is directly linked to the buttons that activate those procedures.

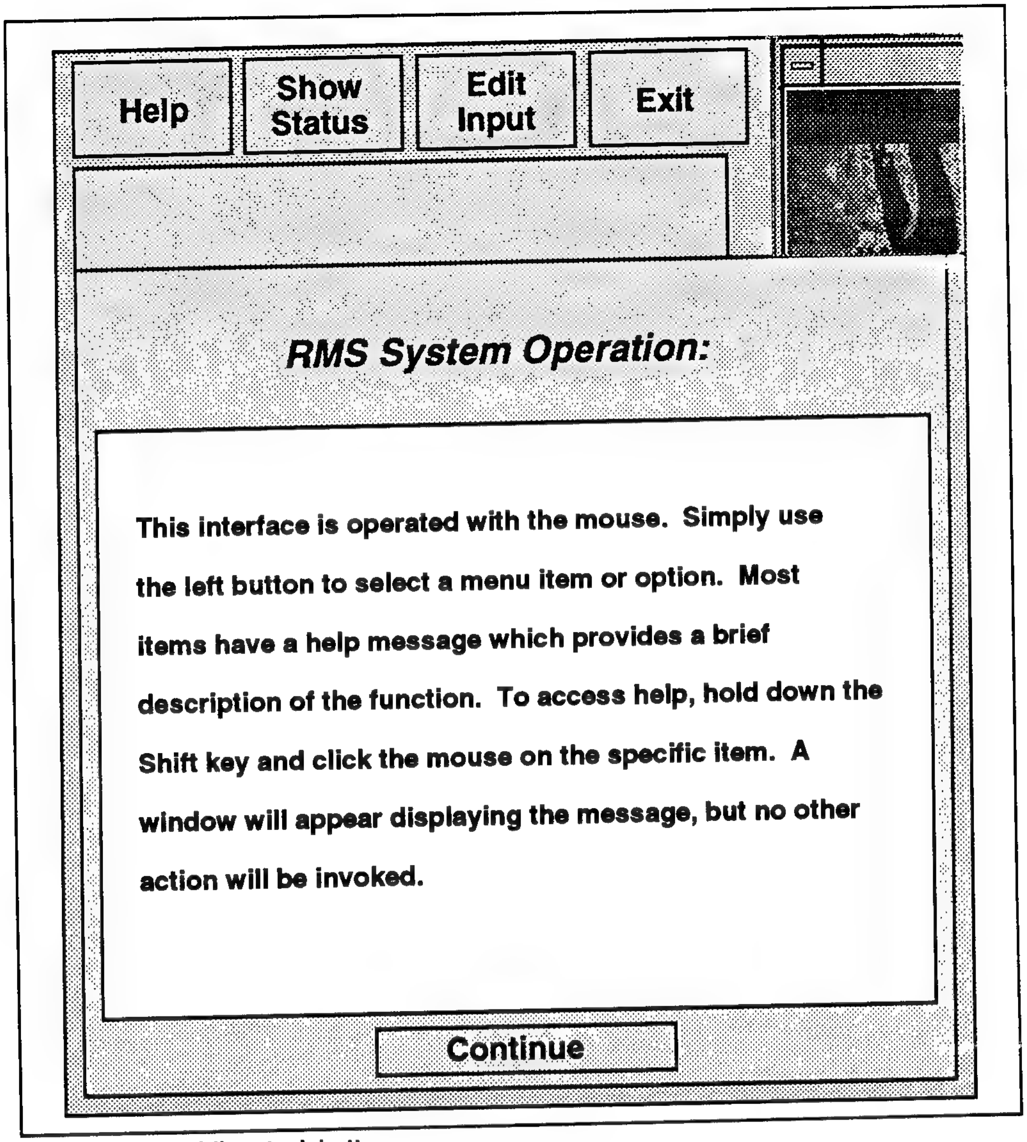

Figure 16. Subsidiary task buttons.

Information Transfer

The GUI improves information transfer between the user and computer by improving the efficiency of inputs and outputs. The GUI reduces the input requirements of the user. Each procedure in the system requires input from another procedure, a data file, or the user. If the source of input is another procedure, then the data is accessed without intervention by the user. Computer algorithms may be used to process information into the next required format. If the source of input is a data file, then the user is prompted to select a file from a display of appropriate files, which also reduces required user input. Where input parameters must be entered directly by the user, spaces for text entry are provided with instructions as to which parameter must be typed in. A potential enhancement would be to provide computer checks to ensure the parameters input by the user fall within the acceptable range.

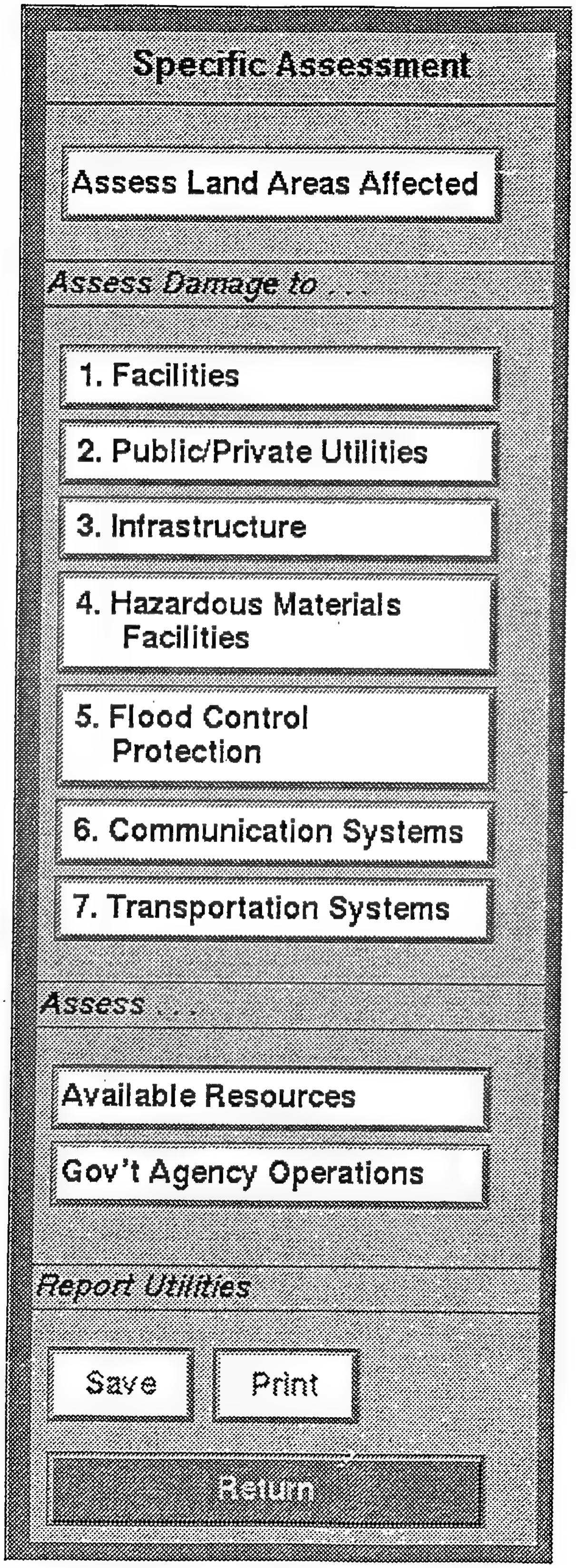

Figure 17. Assessment task board.

Some portions of a model input file, e.g., physical descriptions of a channel network, will not change between model runs. Other parts, e.g., precipitation or base flow values, may need updating. Rather than creating a new input file for each model run, an existing input file may be modified, either automatically or by the user, to reflect the new conditions. The *output* from a standard model run may be extensive and include much nonessential information to the emergency decisionmaker. An interface may be designed to extract immediately useful information.

The GUI directly supports impact assessment, including the query and analysis of geophysical and human resource data. The assessment portion of the interface currently provides samples of the information that can be made available for decisionmaking (Figure 17). As previously stated, it is based on the GIS User Information Requirements compiled by HQUSACE. It was desired that the system display data in the form required to perform the main system task, flood assessment. The user should not have to translate displayed data into this form. Flood depth maps representing historic flood occurrences might be provided to assess the relative magnitude of a potential flood with a past flood and its known impacts.

This portion of the interface can be expanded as information requirements are better established and as databases are created to provide the needed information. Since information needs may vary from location to location, some degree of system and interface customization would be required for implementation at other locations.

Area statistics, site retrieval, and graphical display are currently incorporated into this portion of the interface to demonstrate potential forms of the production of information useful for impact assessment. These functions are described in the proceeding paragraphs.

Area Statistics. The generated flood depth map is used as a tool for the spatial analysis of flood impact. It is specified as a "mask" prior to calculating area statistics for other raster maps. A mask causes only that portion of a map that falls within its boundaries to be displayed and/or used for analysis. A report of flooded land use areas is generated by specifying the flood depth map as a mask, and then running r.report, a GRASS raster report program that calculates area totals for all categories of the displayed or masked portion of the land use raster map. A coincidence program within GRASS, r.coin, calculates the area coincidence of two maps, but reports category *numbers*, rather than labels, and so is not as immediately useful for impact reports. GIS capabilities were also used to calculate affected population. Using r.stats with a population density raster, it was possible to output a report of the total square meters of each population density raster. Using simple UNIX shell scripts, it is possible to multiply densities by these areas, and then sum these to provide a custom report of population affected.

Site Retrieval. Flood depth maps may also be used to mask or filter site lists to determine the particular site types, such as hospitals or schools that fall within the flooded area. Buttons are included within the GUI that immediately extract lists of the facilities of a particular type whose geographic coordinates fall within the predicted flooded area. The display of tabular information aids in the quick retrieval of information needed for use in emergency assessment and response, such as the location of all hazardous material storage sites within the flooded area and the persons to contact with warnings (Figure 18). While GRASS site lists are fine for storing and retrieving small amounts of information, linkage to a separate database system is desirable for storing and extracting the larger datasets required for more extensive flood assessment and emergency response decisions.

Hazardous Material Sites within Flooded Area

Site:	Name:	Address:	Phone:
hazmat	Capitol Food Mart	202 E. Capitol, Pierre 57501	NA
hazmat10	Case Power & Equip	E. Truck Bypass,Pierre 57501	NA
hazmat12	CJ's 66	621 W. Sioux, Pierre 57501	NA
hazmat13	Pierre Farmers Elevation Assn	2810 E. Sioux	NA
hazmat8	7-11 Store	1225 Wells Ave.	NA
hazmat14	Ostlund Chemical Co.	2009 East Sioux,Pierre 57501	NA

Figure 18. Tabular display of emergency assessment and reponse information.

Graphical Display. The RMS interface enhances the user's ability to understand the flood conditions by allowing the graphical display of system output (Figure 19). Common hydraulic and hydrologic models present forecasts as water surface elevations along channel cross sections or hydrographs at point locations. For this information to be meaningful, the decisionmaker would need to have a detailed understanding of the topography of the area being modeled. Flood forecasts are more useful to the decisionmaker when presented in terms of depth and extent. The display section allows flood extent maps to be overlaid with other raster, vector, or site maps (Figure 20) to visually determine which features lie within the predicted flooded area. The capability to simultaneously display maps can also allow the user to compare historic flood maps with those generated by the system. The linked GIS capabilities allow the user to zoom in on areas of interest and to obtain needed geographic coordinates and map categories, such as flood depth, by simply clicking the location with the mouse (Figure 21).

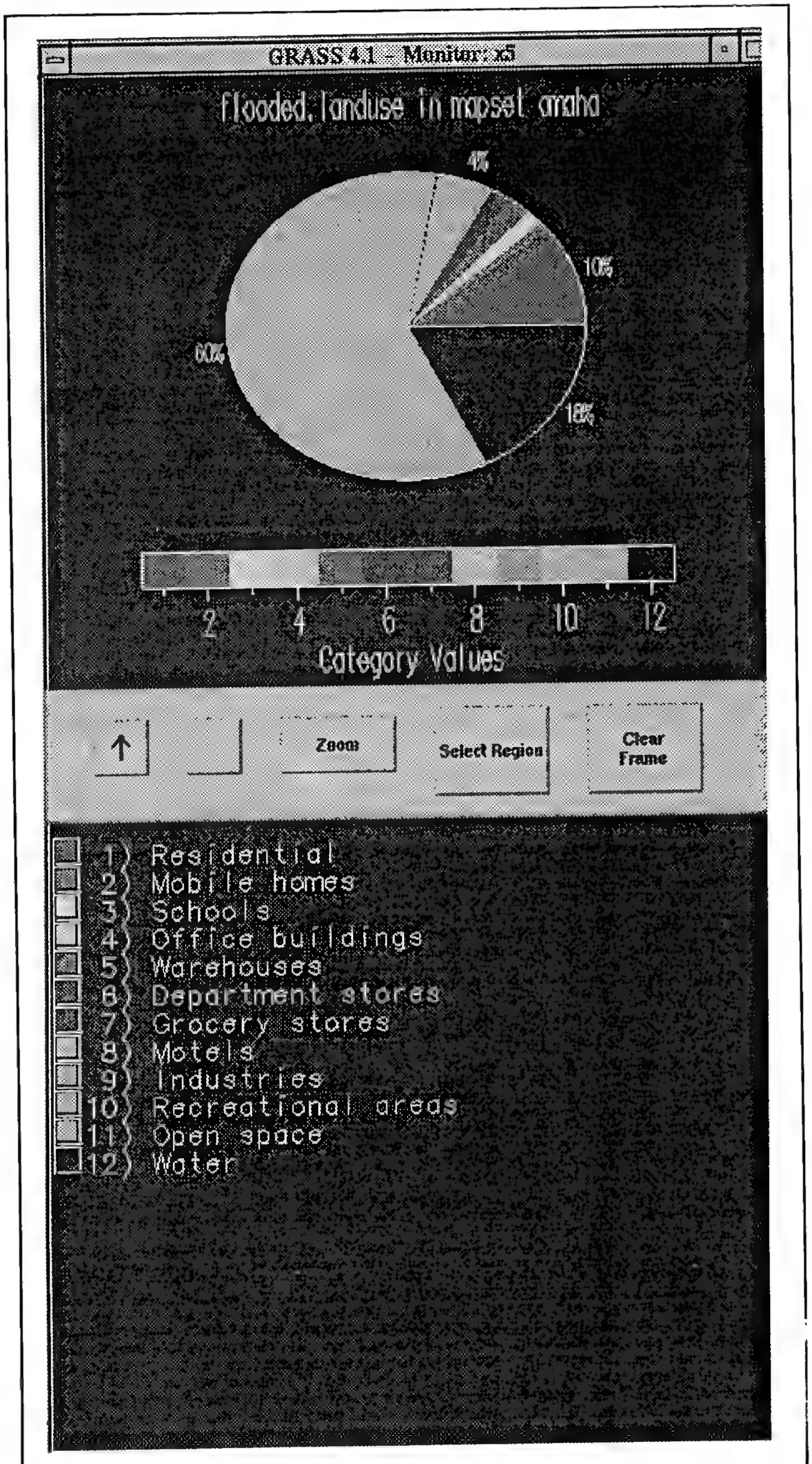

Figure 19. Screen display showing percent of flooded land by use.

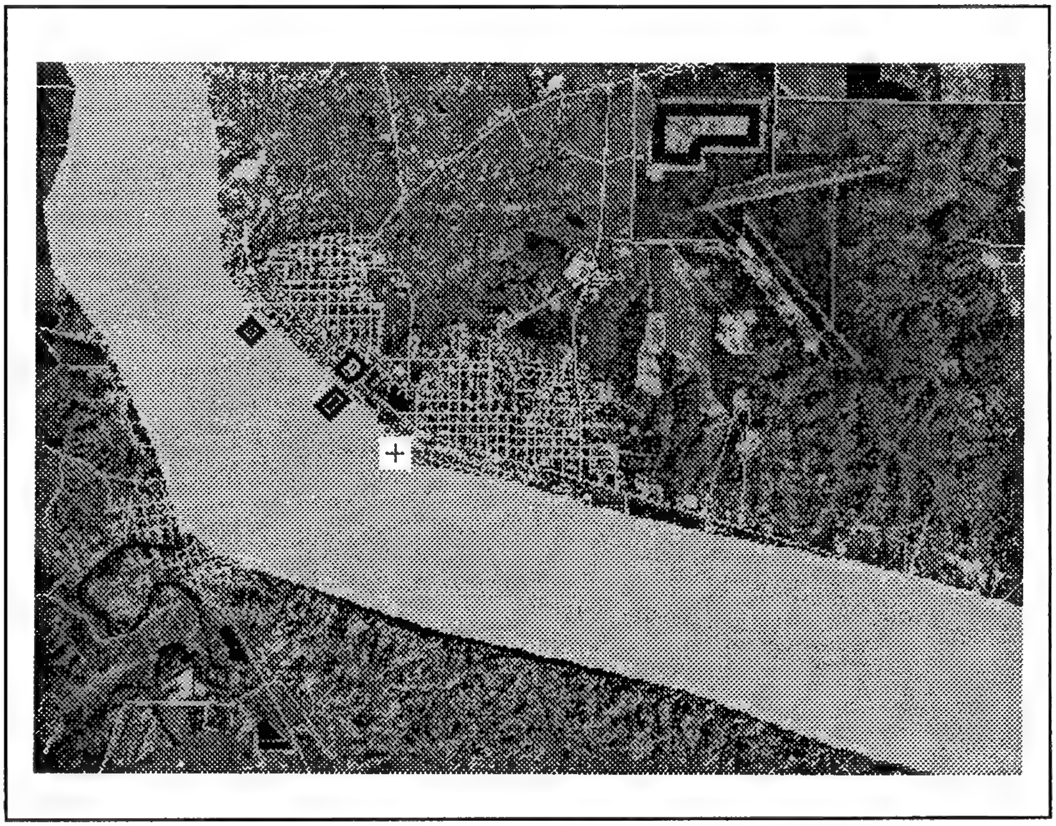

Figure 20. Overlaid flood extend maps identify features within flooded areas.

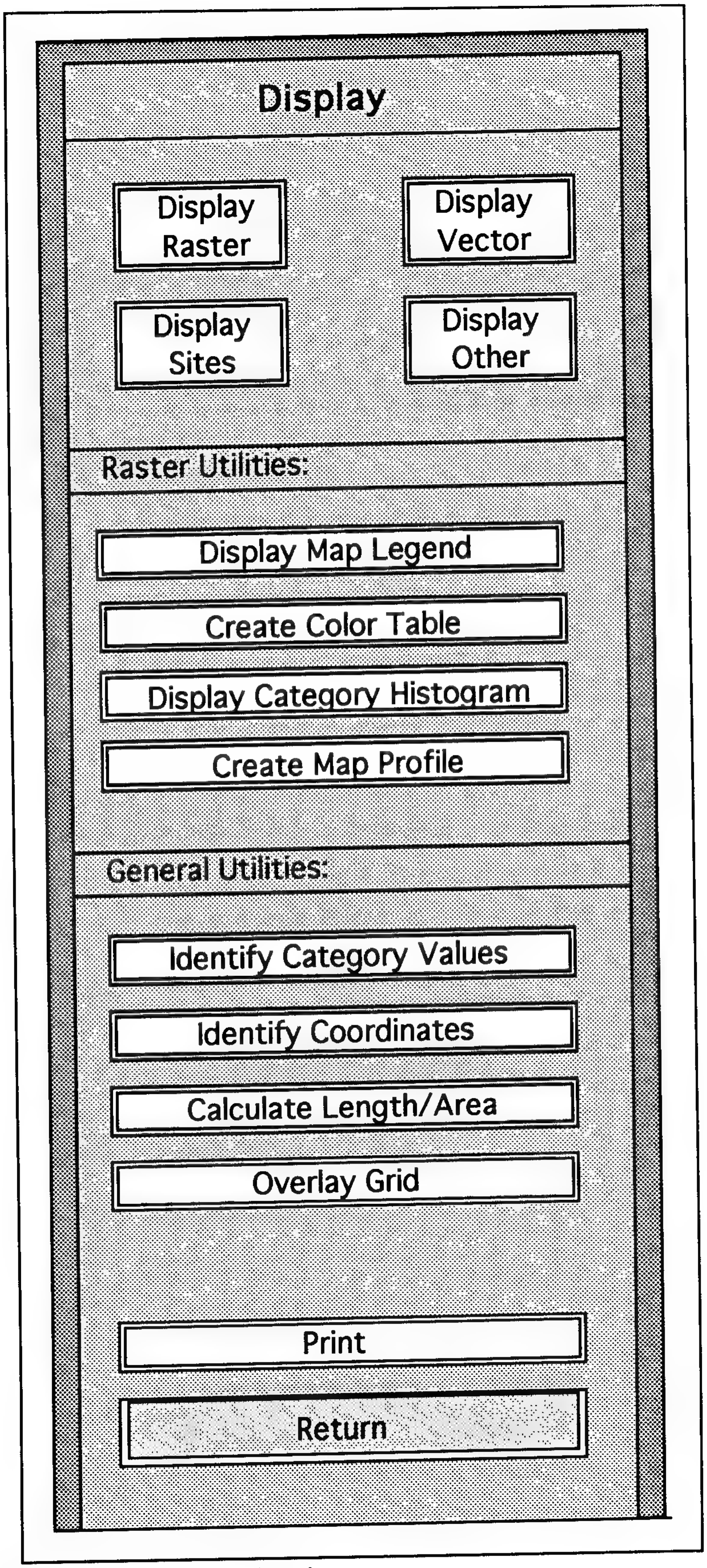

Figure 21. Display task board.

6 Summary and Recommendations

Computer-based systems for real-time flood forecasting may include a number of capabilities, including data acquisition and processing, precipitation analysis, streamflow forecasting, reservoir system analysis, and graphical display of data and simulation results. Incorporating the spatial analysis capabilities of a GIS into flood response systems can increase the effectiveness of such systems by increasing the speed and scale of data manipulation, and enhancing the interpretation of typical hydrologic and hydraulic model output. A GIS may also be used to automate the interpolation of channel water surface elevations into water surface elevation maps, to overlay water surface maps onto topographic maps to determine flood depth, and to identify sites lying within the flooded area. While the use of GIS in conjunction with hydrologic and hydraulic models is not a new concept, it has become more widespread and sophisticated in relation to water resources applications. The potential for using GUI in real-time flood control systems has been recognized by various government agencies and offices.

A GUI that links system components in a unified user envoronment may best address the demands of a complex, multiple-component system and the needs of users with a range of computing and technical skills. The GUI may reduce the number of steps a user must complete by dividing the labor appropriately between the user and the computer. Menial tasks may be automated, and the steps the user needs to take more clearly communicated through an operations chart. In addition to this procedural support, the GUI can give the user decision support by providing rapid access to information critical to emergency response.

This study explored the technical feasibility of creating a link of individual software components into an integrated system for flood prediction and assessment that eliminates the need for the decisionmaker to construct the simulation process, thereby freeing time for evaluating generated information and making decisions. A prototype GUI was created, incorporating several ideal characteristics of emergency management systems, and including the abilities to quickly process, organize, and retrieve large quantities of information into an easily accessible format. The system was also designed to produce a flood map of a current disaster and to model a series of alternative reservoir release scenarios to be tested.

The prototype GUI developed in this study provides procedural support and operational flow charts to help the user understand system tasks through the use of interactive, process-oriented interfaces and conventional GUI tools. The GUI also reduces the number of steps the user must take by automating menial tasks.

The prototype interface was evaluated by Omaha District decisionmakers, who contributed some recommendations for further development. It is recommended that a well-defined sequence of assessment be developed based on further analysis of the flood emergency decisionmaking process. A true decision-support system should both generate information and allow a comparison of alternative decisions. To this end, it is recommended that economic analysis software (incorporating cost/benefit, tradeoff analyses, etc.) be integrated with GIS capabilities.

It is also recommended that the prototype GUI be expanded to include additional user prompts and an expanded online help to give users detailed descriptions of required parameters, and to link the GUI to a common database system to provide access to a larger range of useful decisionmaking data.

It is further recommended that an auto printout capability of information suitable for radio and television announcers be developed.

References

Cited

Brown, B.W., and R.A. Shelton, "TVA's Use of Computers in Water Resource Management," *Journal of Water Resources Planning and Management*, Vol 112, no. 3 (July 1986), pp 409-418.

Buehler, K., *The Xgen Application Generator Program (Version 1.1)* (U.S. Army Construction Engineering Research Laboratories [USACERL], 1992).

Buehler, K., and C. Poulsen, "A Motif-Based Tool for Providing User Interfaces to Common Languages," *Proceedings of Motif '91, Open Systems* (Bethesda, MD), pp 203-217.

Colon, R., and G.F. McMahon, "BRASS Model: Application to Savannah River System Reservoirs," *Journal of Water Resource Planning and Management*, Vol 113, no. 2 (March 1987), pp 177-190.

Cotter, D.M., "Application of Computer Simulation Techniques to Flood Risk Mapping," *Simulation in Emergency Management and Technology*, Vol 20 (The Society for Computer Simulation International, 1989), pp 84-87.

Depodesta, et al., "Floodplain Management Integrating GIS and HEC-2," *Second National Specialty Conference on Civil Engineering Applications of Remote Sensing and Geographic Information Systems*, American Society of Civil Engineers [ASCE], 1991), pp 336-345.

Dodson, R.D., "Distribution and Support of HEC Programs: Vendor Responsibilities," *Transferring Models to Users: Symposium Proceedings* (American Water Resources Association [AWRA], Denver, CO, November 1990), pp 29-234.

Djokic, D., "Towards General Purpose Spatial Decision Support System Using Existing Technologies," paper presented at the *Second International Conference/Workshop on GIS and Environmental Modeling* (Breckenridge, CO, 26-30 September 1993).

Engdahl, T.L., D.H. Bae, and K.P. Georgakakos, "Utilization of Weather Radar for Hydrologic Forecasting," *Water Resources: Planning and Management and Urban Water Resources, Proceedings of the 18th Annual Conference and Symposium*, New Orleans, LA, (May 20-22, 1991), p 405-409.

ESRI, *6.0 ARC/INFO Data Model, Concepts, and Key Terms* (1991).

Fedra, K., "GIS and Environmental Modeling," *First International Symposium/Workshop on GIS and Environmental Modeling* (National Center for Geographic Information and Analysis [NCGIA], Boulder, CO, September 1991).

Feldman, A.D., "Systems Analysis Applications at the Hydrologic Engineering Center," *Journal of Water Resources Planning and Management*, Vol 118, no. 3 (May/June 1992), pp 249-261.

Fischenich, C.J., "Readiness Management System Demonstration Program," *GIS World* (1991).

Fort Worth District, *Prototype Methodology Study: Upper Trinity River Basin* (USACOE, Fort Worth, TX, 1991).

Frysinger, S.P., D.A. Copperman, and J.P. Levantino, "Environmental Decision Support Systems: An Open Architecture Integrating Modeling and GIS," *Second International Conference / Workshop on GIS and Environmental Modeling, Breckenridge, CO* (26-30 September 1993).

HEC, *HECDSS Programmers Manual* (U.S. Army Corps of Engineers, Hydrologic Engineering Center [HEC], Davis, CA, 1987).

HEC, *HEC-1 Flood Hydrograph Package: User's Manual* (HEC, 1990a).

HEC, *HEC-2, Water Surface Profiles User's Manual* (HEC, 1990b).

HEC, *Water Control Software Forecast and Operations* (HEC, 1989).

Hoggan, D.H., T.R. Wood, K.N. Keck, and R.C. Martineau, "Combined Application of HEC-1 and HEC-2 Simulation Models on Dike Safety Analysis," *Proceedings of the 1991 National Conference on Hydraulic Engineering* (ASCE, 1991), pp 1061-1066.

HQUSACE, "User Requirements," *Proceedings of the Meeting of the Emergency Management Information Systems-SDTG* (3-5 March 1992).

Krzysztofowicz, R., "Performance Tradeoff Characteristic of a Flood Warning System," *Water Resources Bulletin*, Vol 28, no. 1 (February 1992).

Krzysztofowicz, R., and D. Davis, "Toward Improving Flood Forecasting Response Systems," *Interfaces*, Vol 14 (May/June 1984), pp 1-14.

Martin, M., W. Goran, R. Lozar, J. Messersmith, M. Ruiz, J. Westervelt, *GRASS / GIS Implementation Guide*, USACERL Special Report, N-90/02/ADA214623 (USACERL, October 1989), p 1.

McCoy, L.C., "Who's in Charge?: How Bureaucratic Lines of Authority Interfere With Modeling and Computer Simulation in Disaster Response," *Computer Simulation in Emergency Planning, Proceedings of the Conference on Computer Simulation in Emergency Planning*, Vol 11, no. 2 (San Diego, 27-29 January 1983), pp 42-44.

McMahon, G.F., "Real-Time Flood Management Model for Highland Lake System," *Journal of Water Resources Planning and Management*, Vol 115 (January 1989), pp 125-7.

Powel, J.E., *Designing User Interfaces* (Microtrend Books, San Marcos, CA, 1990).

Poulsen, C.M., *Graphical User Interfaces for Geographic Information Systems*, Masters Thesis (University of Illinois, Champaign-Urbana, IL, 1992).

Purves, A.J., P.L. Croswell, and T.W. Foresman, "Regional Flood Control District GIS Applications," *Second National Specialty Conference on Civil Engineering Applications of Remote Sensing and Geographic Information Systems* (ASCE, 1991), pp 328-335.

Ratcliff, J., and R. Cunningham, "GIS Applications Floodplain Reconnaissance Studies," *Second National Specialty Conference on Civil Engineering Applications of Remote Sensing and Geographic Information Systems* (ASCE, 1991), pp 87-96.

Shea, C, W. Grayman, D. Darden, R. Males, and P. Sushinsky, "Integrated GIS and Hydrologic Modeling for Countywide Drainage Study," *Journal of Water Resources Planning and Management*, Vol 119, no. 2 (March/April, 1993), pp 112-127.

Scheinderman, B., *Designing the User Interface*, Addison-Wesley, Reading, MA, 1987.

Sutcliffe, A., *Human-Computer Interface Design* (Macmillan Education, Houndsmills, England, 1988).

Thompson, G., P. Byrne, S. Herbert, and J. Young, "Integration of SCADA and GIS Technologies in Jefferson Parish, Louisiana," *Second National Specialty Conference on Civil Engineering Applications of Remote Sensing and Geographic Information Systems* (ASCE, 1991), pp 147-154.

Thimbleby, H., *User Interface Design* (ACM Press, New York, 1990).

Unver, O., L. Mays, and K. Lansey, "Real-Time Flood Management Model for Highland Lake System," *Journal of Water Resource Planning and Management*, Vol 113, no. 5 (September 1987), pp 620-638.

Westervelt, J.D., M. Shapiro, W.D. Goran, D.P. Gerdes, Automated Data Processing (ADP) Report N-87/22/ADA255215, rev., *Geographical Resources Analysis Support System (GRASS) Version 4.0 User's Reference Manual* (USACERL, 1989).

Uncited

Davis, W.D., and V.R. Bonner, "Twenty-Five Years of Developing, Distributing, and Supporting Hydrologic Engineering Computer Programs, *Transferring Models to Users,* Symposium Proceedings, Denver (AWRA, November 1990), pp 221-227.

Lovell, T.L., and W.E. Skipwith, "HEC Technology Transfer to Users: The Good, the Bad, and the Ugly," *Transferring Models to Users*, Symposium Proceedings, Denver (AWRA, November 1990), pp 235-240.

Over, T.M., and H.R. Horsey, "Visualization of Water Resource System Simulation Model Output," *Transferring Models to Users*, AWRA Symposium Proceedings, Denver (AWRA, November 1990), pp 61-71.

Skipwith, W., L. Morland, M. Denton, and M. Askew, "Closing the Floodgates, Floodplain Management Techniques," *Civil Engineering*, Vol 60 (July 1990), pp 54-55.

USACERL DISTRIBUTION

Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: CEHEC-IM-LP (2)
ATTN: CECG
ATTN: CECC-P
ATTN: CECW
ATTN: CECW-O
ATTN: CECW-P
ATTN: CECW-PR
ATTN: CEMP
ATTN: CEMP-E
ATTN: CEMP-C
ATTN: CEMP-M
ATTN: CEMP-R
ATTN: CERD-C
ATTN: CERD-ZA
ATTN: CERD-L
ATTN: CERD-M
ATTN: CERM
ATTN: DAEN-ZC
ATTN: DAIM-FDP

CECPW 22310-3862
ATTN: CECPW-E
ATTN: CECPW-FT
ATTN: CECPW-ZC
ATTN: DET III 79906

US Army Engr District
ATTN: Library (40)

US Army Engr Division
ATTN: Library (12)

US Army Europe
ATTN: AEAEN-EH 09014
ATTN: AEAEN-ODCS 09014
Frankfurt Base Support Battalion
ATTN: Unit 25727 09242
CMTC Hohenfels 09173
ATTN: AETTH-DPW
21st Support Command
ATTN: DPW (10)
US Army Berlin
ATTN: AEBA-EH 09235
ATTN: AEBA-EN 09235
SETAF
ATTN: AESE-EN-D 09613
ATTN: AESE-EN 09630
Supreme Allied Command
ATTN: ACSGEB 09703
ATTN: SHIHB/ENGR 09705

INSCOM
ATTN: IALOG-I 22060
ATTN: IAV-DPW 22186

USA TACOM 48397-5000
ATTN: AMSTA-XE

Defense Distribution Region East
ATTN: DDRE-WI 17070

US Army Materiel Command (AMC)
Alexandria, VA 22333-0001
ATTN: AMCEN-F
Rock Island Arsenal 61299
ATTN: SMCRI-EH
ATTN: SMCRI-TL
Watervliet Arsenal 12189
ATTN: SMCWV-EH
Red River Army Depot 76102
ATTN: SDSRR-G
White Sands Missile Range 88002
ATTN: Library

FORSCOM
Forts Gillem & McPherson 30330
ATTN: FCEN
Fort Riley 66442
ATTN: AFZN-DE
Fort Polk 71459
ATTN: AFZX-DE
Fort Lewis 98433
ATTN: AFZH-DE
Fort Carson 80913
ATTN: AFZC-FE
Fort Bragg 28307
ATTN: AFZA-DE
Fort Campbell 42223
ATTN: AFZB-DPW
Fort McCoy 54656
ATTN: AFZR-DE
Fort Stewart 31314
ATTN: AFZP-DEF
Fort Drum 13602
ATTN: AFZS-EH
Fort Irwin 92310
ATTN: AFZJ-EH
Fort Hood 76544
ATTN: AFZF-DE
Fort Meade 20755
ATTN: AFKA-ZI-EH

TRADOC
Fort Monroe 23651
ATTN: ATBO-G
Installations: (20)

Fort Belvoir 22060
ATTN: CETEC-IM-T
ATTN: CECC-R 20314-1000
ATTN: Engr Strategic Studies Ctr
ATTN: Water Resources Support Ctr
ATTN: Australian Liaison Office

USA Natick RD&E Center 01760
ATTN: STRNC-DT
ATTN: DRDNA-F

CEWES 39180
ATTN: Library

CECRL 03755
ATTN: Library

USAARMC 40121
ATTN: ATZIC-EHA

Fort Leonard Wood 65473
ATTN: ATSE-DAC-LB (3)
ATTN: ATZA-TE-SW
ATTN: ATSE-CFLO
ATTN: ATSE-DAC-FL

US Army ARDEC 07806
ATTN: SMCAR-ISE

Engr Societies Library
ATTN: Acquisitions 10017

National Guard Bureau 20310
ATTN: NGB-ARI

US Military Academy 10996
ATTN: MAEN-A
ATTN: Facilities Engineer
ATTN: Geography & Envr Engrg

Naval Facilities Engr Command
ATTN: Facilities Engr Command (8)
ATTN: Division Offices (11)
ATTN: Public Works Center (8)
ATTN: Naval Constr Battalion Ctr 93043
ATTN: Naval Facilities Engr Service Center 93043-4328

Tyndall AFB 32403
ATTN: HQAFCESA Program Ofc
ATTN: Engrg & Srvc Lab

American Public Works Assoc. 64104-1806

US Army Envr Hygiene Agency
ATTN: HSHB-ME 21010

US Gov't Printing Office 20401
ATTN: Rec Sec/Deposit Sec (2)

Nat'l Institute of Standards & Tech
ATTN: Library 20899

Defense Tech Info Center 22304
ATTN: DTIC-FAB (2)

200
10/94

This publication was reproduced on recycled paper.

☆ U.S. GOVERNMENT PRINTING OFFICE: 1994—3510-S/00080